

Chapter 6

Core-Collapse Supernova Neutrinos

sn-chap
2

1 Neutrinos emitted in the first few seconds of a core-collapse supernova carry with them
the potential for great insight into the mechanisms behind some of the most spectacular
events that have played key roles in the evolution of the Universe. Collection and analysis
of this high-statistics neutrino signal from a supernova within our galaxy would provide a
rare opportunity to witness the energy and flavor development of the burst as a function of
time. This would in turn shed light on the astrophysics of the collapse as well as on neutrino
properties.

1

2 6.1 The Neutrino Signal and Astrophysical Phenomena

1 A core-collapse supernova* occurs when a massive star reaches the end of its life, and stellar
1 burning can no longer support the star's weight. This catastrophic collapse results in a compact
1 remnant such as a neutron star, or possibly a black hole, depending on the mass of the progenitor.

1 The infall is followed by a *bounce* when sufficiently high core density is reached, and in some
1 unknown (but nonzero) fraction of cases, the shock wave formed after the bounce results in a
1 bright explosion [195]. The explosion energy represents only a small fraction of the enormous
2 total gravitational binding energy of the resulting compact remnant, however — thanks to the
3 neutrinos' weak coupling, which allows them to escape — within a few tens of seconds almost all
4 of the energy is emitted in the form of neutrinos in the tens-of-MeV range. In spite of their weak
5 coupling, the neutrinos are copious enough to (very likely) play a significant role in the explosion.

6 Neutrinos from the celebrated SN1987A core collapse [103,104] in the Large Magellanic Cloud
7 outside the Milky Way were observed; however, the statistics were sparse and a great many ques-
8 tions remain. A high-statistics observation of a neutrino burst from a nearby supernova would be
9 possible with the current generation of detectors. Such an observation would shed light on the na-
10 ture of the astrophysical event, as well as on the nature of neutrinos themselves. Sensitivity to the
11 different flavor components of the flux is highly desirable.

12 The core-collapse neutrino signal starts with a short, sharp *neutronization* burst primarily com-
13 posed of ν_e (originating from $p + e^- \rightarrow n + \nu_e$, as protons and electrons get squeezed together),
14 and is followed by an *accretion* phase lasting some hundreds of milliseconds, as matter falls onto
15 the collapsed core. The later *cooling* phase over ~ 10 seconds represents the main part of the signal,
16 over which the proto-neutron star sheds its gravitational binding energy. The neutrino flavor con-

*Supernova always refers to a *core-collapse supernova* in this chapter unless stated otherwise.

tent and spectra change throughout these phases, and the supernova's temperature evolution can be followed with the neutrino signal. Some fairly generic supernova signal features are illustrated in Figure 6.1, based on [196] and reproduced from [197].

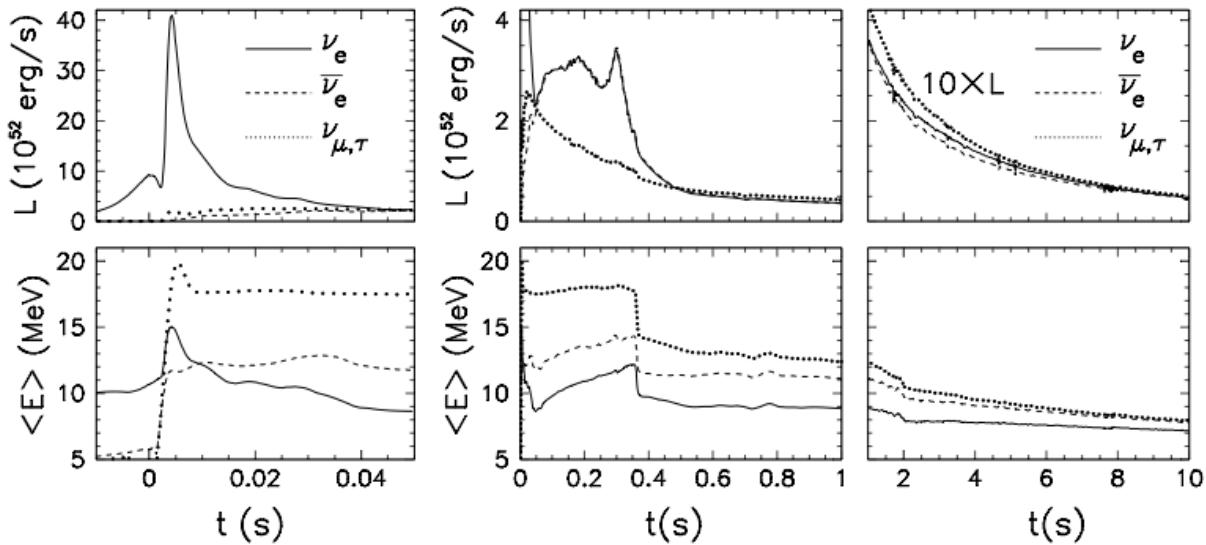


Figure 6.1: Expected core-collapse neutrino signal from the *Basel* model [196], for a $10.8 M_{\odot}$ progenitor. The left plots show the very early signal, including the neutronization burst; the middle plots show the accretion phase, and the right plots show the cooling phase. Luminosities as a function of time are shown across the top plots. The bottom plots show average energy as a function of time for the ν_e , $\bar{\nu}_e$ and $\nu_{\mu,\tau}$ flavor components of the flux (fluxes for ν_{μ} , $\bar{\nu}_{\mu}$, ν_{τ} , and $\bar{\nu}_{\tau}$ should be identical). Figure courtesy of [197].

19

The supernova-neutrino spectrum at a given moment in time is expected to be well described by a parameterization [198,199] given by:

$$\phi(E_{\nu}) = \mathcal{N} \left(\frac{E_{\nu}}{\langle E_{\nu} \rangle} \right)^{\alpha} \exp \left[-(\alpha + 1) \frac{E_{\nu}}{\langle E_{\nu} \rangle} \right], \quad (6.1)$$

where E_{ν} is the neutrino energy, $\langle E_{\nu} \rangle$ is the mean neutrino energy, α is a *pinching parameter*, and \mathcal{N} is a normalization constant. Large α corresponds to a more pinched spectrum (suppressed high-energy tail). This parameterization is referred to as a *pinched-thermal* form. The different ν_e , $\bar{\nu}_e$ and ν_x , $x = \mu, \tau$ flavors are expected to have different average energy and α parameters and to evolve differently in time.

A wide variety of astrophysical phenomena affect the flavor-energy-time evolution of the spectrum, including neutrino oscillation effects that are determined by the mass hierarchy (MH) and collective effects due to neutrino-neutrino interactions. A voluminous literature exists exploring these collective phenomena, e.g., [200,201,202,203,204,205,206,207,208].

29

A number of astrophysical phenomena associated with supernovae are expected to be observable in the supernova-neutrino signal, providing a remarkable window into the event, for example:

- The initial burst, primarily composed of ν_e and called the *neutronization* or *breakout* burst, represents only a small component of the total signal. However, oscillation effects can manifest in an observable manner in this burst, and flavor transformations can be modified by the *halo* of neutrinos generated in the supernova envelope by scattering [209].
Cherry:2013mv
- The formation of a black hole would cause a sharp signal cutoff (e.g., [210,211]).
Beacom:2000qy, Fischer:2008r
- Shock wave effects (e.g., [212]) would cause a time-dependent change in flavor and spectral composition as the shock wave propagates.
Schirato:2002tg
- The standing accretion shock instability (SASI) [213,214], a *sloshing* mode predicted by 3D neutrino-hydrodynamics simulations of supernova cores, would give an oscillatory flavor-dependent modulation of the flux.
Hanke:2011jf, Hanke:2013ena
- Turbulence effects [215,216] would also cause flavor-dependent spectral modification as a function of time.
Friedland:2006ta, Lund:2013uta

30

This list is far from comprehensive. Furthermore, signatures of *collective* effects and signatures that depend on the MH will make an impact on many of the above signals (examples will be presented in Section 6.2). Certain phenomena are even postulated to indicate beyond-the-Standard-Model physics [217] such as axions, extra dimensions and an anomalous neutrino magnetic moment; non-observation of these effects, conversely, would enable constraints on these phenomena.

The supernova-neutrino burst signal is prompt with respect to the electromagnetic signal and therefore can be exploited to provide an early warning to astronomers [116,117]. Additionally, a LArTPC signal [218] is expected to provide some pointing information, primarily from elastic scattering on electrons.
Antonelli:2004zb, Scholberg:2008fa, Bilenko:2003ei, Raffelt:1999tx

Even non-observation of a burst, or non-observation of a ν_e component of a burst in the presence of supernovae (or other astrophysical events) observed in electromagnetic or gravitational wave channels, would still provide valuable information about the nature of the sources. Moreover, a long-timescale, sensitive search yielding no bursts will also provide limits on the rate of core-collapse supernovae.
Antonelli:2004zb, Scholberg:2008fa, Bilenko:2003ei, Raffelt:1999tx

6.2 Expected Signal and Detection in Liquid Argon

- As discussed in Section 2.4, liquid argon is known to exhibit a singular sensitivity to the ν_e component of a supernova-neutrino burst. This feature is especially important, as it will make LBNE a unique source in the global effort to combine data from a variety of detectors with different flavor sensitivities to obtain a complete picture of the physics of the burst.

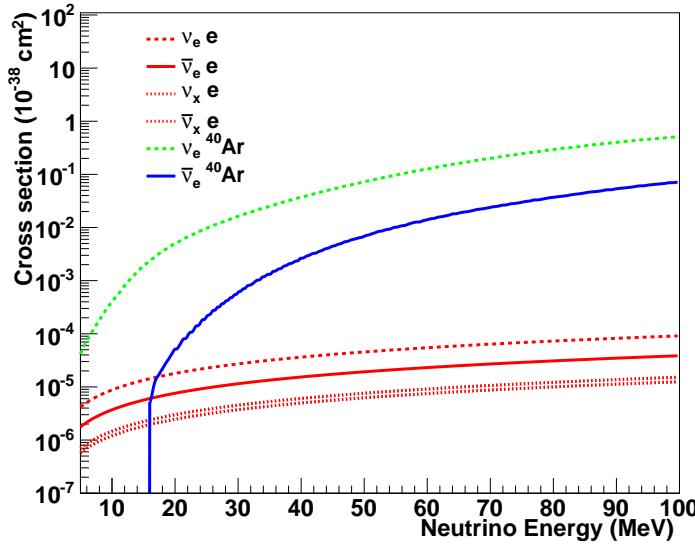


Figure 6.2: Cross sections for supernova-relevant interactions in argon.

The predicted event rate from a supernova-neutrino burst may be calculated by folding expected neutrino differential energy spectra in with cross sections for the relevant channels, and with detector response. For event rate estimates in liquid argon, a detection threshold of 5 MeV is assumed. The photon-detection system of the LBNE far detector, coupled with charge collection and simple pattern recognition, is expected to provide a highly efficient trigger. Most LBNE supernova physics sensitivity studies so far have been done using parameterized detector responses from [139] implemented in the SNOwGLoBES software package [219]. SNOwGLoBES takes as input fluxes, cross sections (Figure 6.2), *smearing matrices* (that incorporate both interaction product spectra and detector response) and post-smearing efficiencies. The energy resolution used is

$$\frac{\sigma}{E \text{ (MeV)}} = \frac{11\%}{\sqrt{E \text{ MeV}}} + 2\% \quad (6.2)$$

- Work is currently underway using the full Geant4 simulation [132] framework and the LArSoft software package [220] to characterize low-energy response for realistic LBNE detector configurations. Preliminary studies of the detector response with the full simulation are summarized in Section A.1.2 and are found to be consistent with the parameterized response implemented in SNOwGLoBES.

¹⁴ Table 6.1 shows rates calculated with SNOWGLOBES for the dominant interactions in argon for
¹⁵ the Livermore model [221], and the GKVM model [222]. Figure 6.3 shows the expected observed
 differential event spectra for these fluxes. Clearly, the ν_e flavor dominates.

Table 6.1: Event rates for different supernova models in 34 kt of liquid argon for a core collapse at 10 kpc, for ν_e and $\bar{\nu}_e$ charged-current channels and elastic scattering (ES) on electrons. Event rates will simply scale by active detector mass and inverse square of supernova distance.

ab:argon_events

Channel	Events	
	Livermore model	GKVM model
$\nu_e + {}^{40}\text{Ar} \rightarrow e^- + {}^{40}\text{K}^*$	2308	2848
$\bar{\nu}_e + {}^{40}\text{Ar} \rightarrow e^+ + {}^{40}\text{Cl}^*$	194	134
$\nu_x + e^- \rightarrow \nu_x + e^-$	296	178
Total	2794	3160

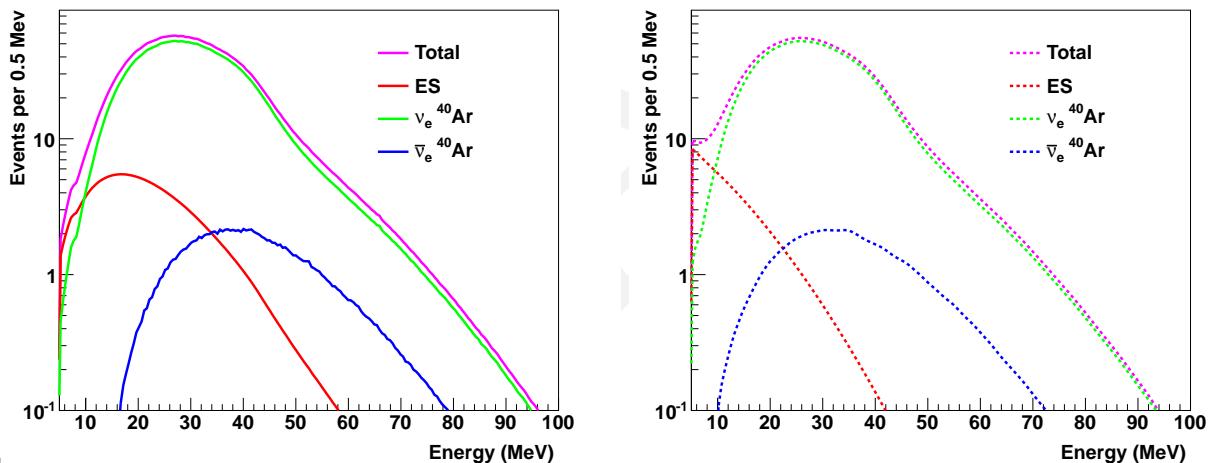


Figure 6.3: Supernova-neutrino event rates in 34 kt of argon for a core collapse at 10 kpc, for the GKVM model [222] (events per 0.5 MeV), showing three relevant interaction channels. Left: interaction rates as a function of true neutrino energy. Right: smeared rates as a function of detected energy, assuming resolution from [139].

16

¹⁷ Figure 6.4 gives another example of an expected burst signal, for which a calculation with detailed
¹⁸ time dependence of the spectra is available [223] out to nine seconds post-bounce. This model
¹⁹ has relatively low luminosity but a robust neutronization burst. Note that the relative fraction of
²⁰ neutronization-burst events is quite high.

²¹ In Figure 6.5, different oscillation hypotheses have been applied to Duan fluxes [208]. The Duan
²² flux represents only a single late time slice of the supernova-neutrino burst and not the full flux;
²³ MH information will be encoded in the time evolution of the signal, as well. The figure illustrates,
²⁴ if only anecdotally, potential MH signatures.

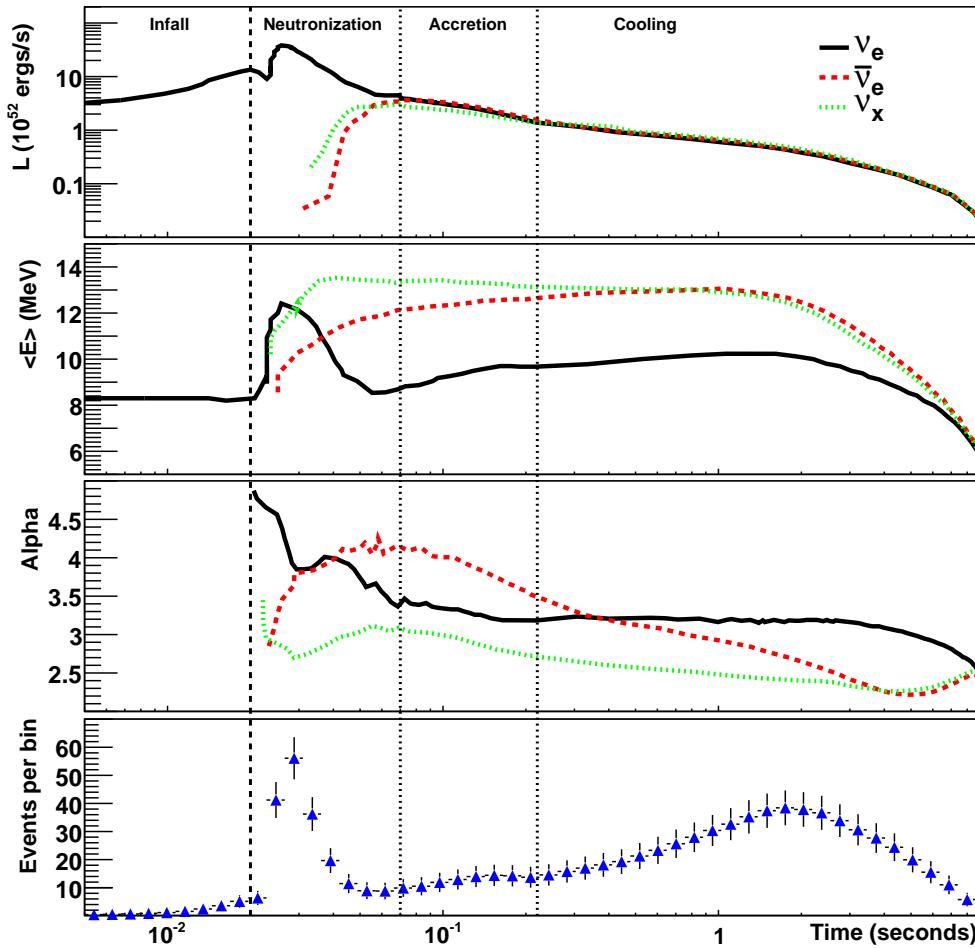


Figure 6.4: Expected time-dependent signal for a specific flux model for an electron-capture supernova [223] at 10 kpc. The top plot shows the luminosity, the second plot shows average neutrino energy, and the third plot shows the α (pinching) parameter. The fourth (bottom) plot shows the total number of events (mostly ν_e) expected in 34 kt of liquid argon, calculated using SNoWGLoBES. Note the logarithmic binning in time; the plot shows the number of events expected in the given bin and the error bars are statistical. The vertical dashed line at 0.02 seconds indicates the time of core bounce, and the vertical lines indicate different eras in the supernova evolution. The leftmost time interval indicates the infall period. The next interval, from core bounce to 50 ms, is the neutronization burst era, in which the flux is composed primarily of ν_e . The next period, from 50 to 200 ms, is the accretion period. The final era, from 0.2 to 9 seconds, is the proto-neutron-star cooling period.

Another potential MH signature is shown in Figure 6.6, for which a clear time-dependent shock-wave-related feature is visible for the normal MH case.

Figure 6.7 shows yet another example of a preliminary study showing how one might track supernova temperature as a function of time with the ν_e signal in liquid argon. Here, a fit is made to the pinched-thermal form of Equation 6.1. Not only can the internal temperature of the supernova be effectively measured, but the time evolution is observably different for the different hierarchies.

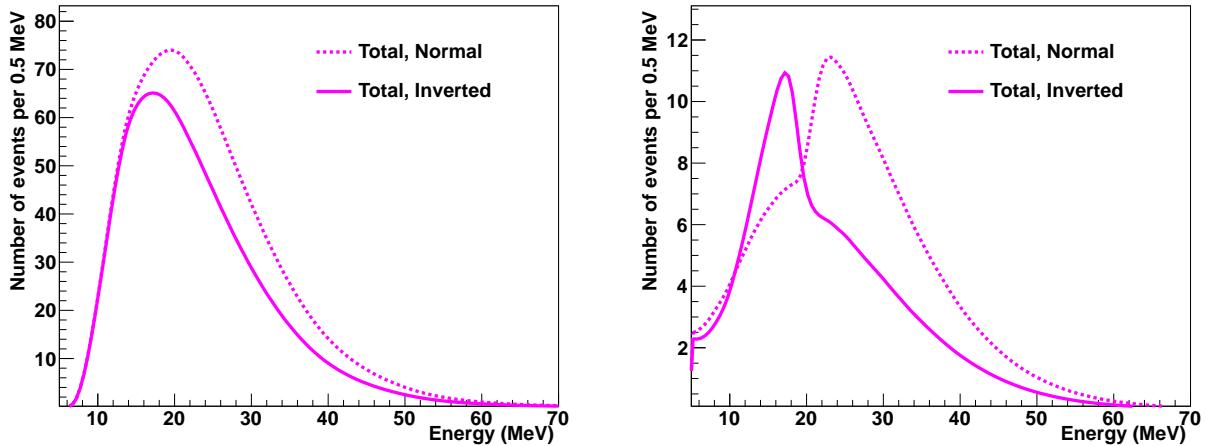


Figure 6.5: Comparison of total event rates for normal and inverted MH, for a specific flux example, for a 100-kt water Cherenkov detector (left) and for a 34-kt LArTPC (right), in events per 0.5 MeV. There are distinctive features in liquid argon for different neutrino mass hierarchies for this supernova model [224].

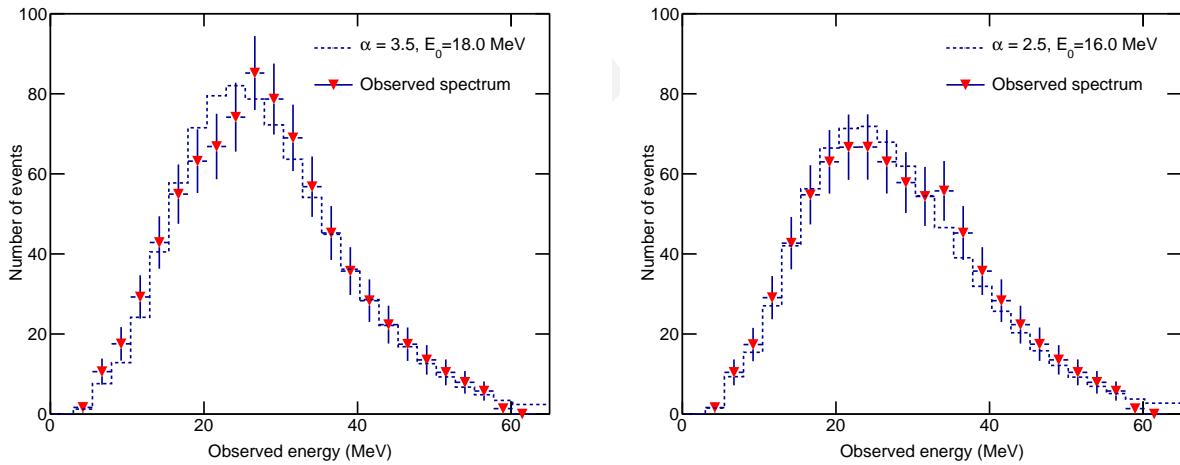


Figure 6.6: Observed ν_e spectra in 34 kt of liquid argon for a 10-kpc core collapse, representing about one second of integration time each at one-second intervals during the supernova cooling phase. The dashed line represents the best fit to a parameterized pinched-thermal spectrum. Clear *non-thermal* features in the spectrum that change with time are visible, on the left at around 20 MeV and on the right at around 35 MeV. Error bars are statistical. These features are present *only* for the normal MH.

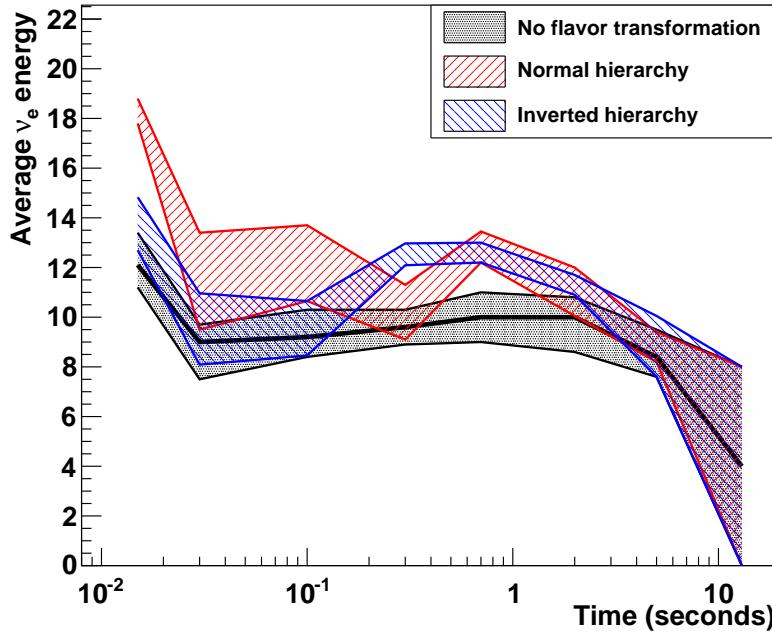


Figure 6.7: Average ν_e energy from fit to SNOWGLOBE-smeared, pinched-thermal spectrum as a function of time (34 kt at 10 kpc), for a flux model based on [225] and including collective oscillations, for two different MH assumptions. The bands represent 1σ error bars from the fit. The solid black line is the truth $\langle E_\nu \rangle$ for the unoscillated spectrum. Clearly, meaningful information can be gleaned by tracking ν_e spectra as a function of time.

6.3 Low-Energy Backgrounds

6.3.1 Cosmic Rays

Due to their low energy, supernova-neutrino events are subject to background from cosmic rays, although the nature of the signal — a short-timescale burst — is such that the background from these muons and their associated Michel electrons can in principle be well known, easily distinguished and subtracted. Preliminary studies [226] suggest that the shielding provided by the 4,850-ft depth available at the Sanford Underground Research Facility is acceptable.

6.3.2 Local Radiation Sources

It is possible that radioactive decays will directly overlap with the energy spectrum created by supernova-neutrino events in LBNE. It is also possible for an ensemble of radioactive-decay events in and around higher-energy particle interactions (e.g., from beam neutrinos) to obscure the edges of electromagnetic showers from highly scattering particles such as electrons and pions; this would appear as the radiological equivalent of dark noise in a digital image, and could potentially intro-

duce a systematic uncertainty in the energy calculated for events, even at much higher energy than the decays themselves. It is therefore very important to calculate the radioactive-decay backgrounds in the LBNE far detector with sufficient accuracy to properly account for their presence, either as direct backgrounds or as systematic effects in energy calculations. To this end, LBNE collaborators are in the process of creating a physics-driven, radioactive-background budget and associated event generator for low-energy background events in the far detector.

The radioactive-background budget will have many components, each of which will fall into one of two categories:

1. intrinsic radioactive contamination in the argon or support materials, or
2. cosmogenic radioactivity produced *in situ* from cosmic-ray showers interacting with the argon or the support materials.

The former is dependent on the detector materials, and is therefore independent of far detector depth. The latter is strongly coupled to the cosmic-ray flux and spectrum. A preliminary estimate [227] of the cosmogenic radioactivity from beta emitters produced from cosmic-ray interactions with argon in the LBNE far detector at the 4,850 ft level of the Sanford Underground Research Facility is shown in Figure 6.8. Both of these background categories add to the direct energy depositions from cosmic rays themselves and associated showers.

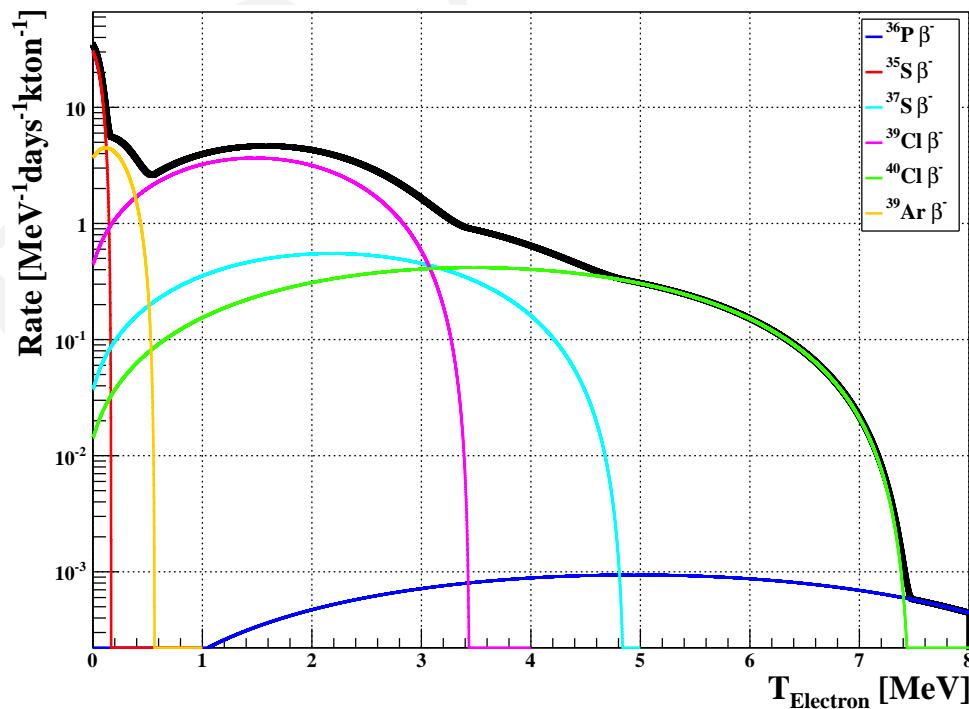


Figure 6.8: Cosmogenic background rates in the LBNE LArTPC as a function of the decay beta kinetic energy calculated at the 4,850-ft level of the Sanford Underground Research Facility.

³² 6.3.3 Intrinsic Radioactive Background Mitigation

Intrinsic

Intrinsic backgrounds in the far detector come from the radioactive material that is prevalent in the detector materials (both active and instrumentation/support materials and the cryostat itself), in the cavern walls and in the dust [228]. The isotopes of primary interest are “the usual suspects” in experiments where radioactive backgrounds must be controlled: ^{232}Th and ^{238}U (and their associated decay chains), ^{40}K , and ^{60}Co . In addition, ^{39}Ar will contribute a significant component, since it is present in natural argon harvested from the atmosphere at the level of approximately 1 Bq/kg. In consequence, a 10-kt far detector filled with $^{\text{nat.}}\text{Ar}$ will experience a rate from ^{39}Ar of approximately 10 MHz across the whole detector. The beta decay spectrum from ^{39}Ar is thankfully quite low in energy ($Q_\beta = 0.565$ MeV), so it will not interfere directly with the supernova signal, but it may contribute to the *dark noise* effect. Furthermore, the product of the average beta energy with this rate indicates the level at which the background due to introduction of power into the detector becomes a problem. This radioactive power from ^{39}Ar is approximately:

$$P_{\text{Rad}} \sim 0.25 \text{ MeV} \times 10 \text{ MHz} = 2.5 \times 10^6 \text{ MeV/s.} \quad (6.3)$$

³³ Because this category of background can come from the cavern walls, the concrete cavern lining,
³⁴ the cryostat materials or the materials that compose the submersed instrumentation, it is important
³⁵ to know which type of radioactive decay is produced by each isotope as well as the total energy
³⁶ it releases. For instance, an alpha decay from an isotope in the U or Th decay chain will deposit
³⁷ its full energy into the detector if it occurs in the active region of the detector, but will deposit no

¹ energy if it occurs inside of some macroscopically thick piece of support material because of its
² very short range ($\lesssim 1 \mu\text{m}$) in most solids. This requires different accounting for energy depositions
³ from intrinsic radioactive contamination measured in different locations (or groups of locations).
⁴ This is clearly a tractable problem, but one which must be handled with care and forethought.

⁵ Since a large body of work has been compiled on the control of radiological background in pre-
⁶ vious experiments that have encountered similar conditions, much of the work in this area will
⁷ be cited from these experiments (e.g., DARKSIDE [229], EXO [230], ICARUS, BOREXINO,
⁸ KamLAND and Super-Kamiokande). Work remains, however, on understanding the background
⁹ particular to the LBNE far detector location/depth (e.g., radon levels and dust activity, for instance),
¹⁰ and on integrating existing and new work into the LBNE simulation, reconstruction and analysis
¹¹ framework.

¹² 6.4 Summary of Core-Collapse Supernova Sensitivities

¹³

LBNE, with its high-resolution LArTPC far detector, is uniquely sensitive to the ν_e component of the neutrino flux from a core-collapse supernova within our galaxy. The ν_e component of the neutrino flux dominates the initial neutronization burst of the supernova. Preliminary studies indicate that such a supernova at a distance of 10 kpc would produce \sim 3,000 events in a 34-kt LArTPC. The time dependence of the signal will allow differentiation between different neutrino-driven core-collapse dynamical models, and will exhibit a discernible dependence on the neutrino mass hierarchy.

A low energy threshold of \sim 5 MeV will enable the detector to extract the rich information available from the ν_e supernova flux. LBNE's photon detection system is being designed to provide a high-efficiency trigger for supernova events. Careful design and quality control of the detector materials will minimize low-energy background from radiological contaminants.

¹⁴¹⁵

REFERENCES

1. “APS Division of Particles and Fields Community Summer Study 2013,” 2013. <http://www.snowmass2013.org>. Cited in Sections 1.1 (pg.4), 1.2.1 (pg.6), and B (pg.235).
2. M. Diwan and C. Jung, “Next generation nucleon decay and neutrino detector. Proceedings, Workshop, NNN99, Stony Brook, USA, September 23-25, 1999,” 2000. Cited in Section 1.2 (pg.5).
3. W. J. Marciano, “Extra long baseline neutrino oscillations and CP violation,” BNL-HET-01-31, arXiv:hep-ph/0108181 [hep-ph], 2001. Cited in Section 1.2 (pg.5).
4. R. Shrock, “Neutrinos and implications for physics beyond the standard model. Proceedings, Conference, Stony Brook, USA, October 11-13, 2002,” 2003. Cited in Section 1.2 (pg.5).
5. M. Diwan, W. Marciano, W. Weng, D. Beavis, M. Brennan, *et al.*, “Report of the BNL neutrino working group: Very long baseline neutrino oscillation experiment for precise determination of oscillation parameters and search for $\nu\mu \rightarrow \nu e$ appearance and CP violation,” BNL-69395, arXiv:hep-ex/0211001 [hep-ex], 2002. Cited in Section 1.2 (pg.5).
6. M. Diwan, D. Beavis, M.-C. Chen, J. Gallardo, S. Kahn, *et al.*, “Very long baseline neutrino oscillation experiments for precise measurements of mixing parameters and CP violating effects,” *Phys. Rev. D* **68** (2003) 012002, arXiv:hep-ph/0303081 [hep-ph]. Cited in Section 1.2 (pg.5).

- 36 7. W. Weng, M. Diwan, D. Raparia, J. Alessi, D. Barton, *et al.*, “The AGS-Based Super
37 Neutrino Beam Facility Conceptual Design Report,” BNL-73210-2004-IR, 2004. Cited in
1 Section 1.2 (pg.5).
- 2 8. M. Diwan, S. H. Kettell, L. Littenberg, W. Marciano, Z. Parsa, *et al.*, “Proposal for an
3 Experimental Program in Neutrino Physics and Proton Decay in the Homestake
4 Laboratory,” BNL-76798-2006-IR, arXiv:hep-ex/0608023 [hep-ex], 2006. Cited in
5 Section 1.2 (pg.5).
- 6 9. V. Barger, M. Bishai, D. Bogert, C. Bromberg, A. Curioni, *et al.*, “Report of the US long
7 baseline neutrino experiment study,” FERMILAB-0801-AD-E, BNL-77973-2007-IR,
8 arXiv:0705.4396 [hep-ph], 2007. Cited in Section 1.2 (pg.5).
- 9 10. N. R. C. Neutrino Facilities Assessment Committee, *Neutrinos and Beyond: New Windows
10 on Nature*. The National Academies Press, 2003. ISBN 0-309-08716-3. Cited in
11 Section 1.2 (pg.5).
- 12 11. Interagency Working Group on the Physics of the Universe. National Science and
13 Technology Council Committee on Science, “A 21st Century Frontier of Discovery: The
14 Physics of the Universe, a Strategic Plan for Federal Research at the Intersection of Physics
15 and Astronomy.”. February, 2004.
16 http://pcos.gsfc.nasa.gov/docs/Physics_of_the_Universe.pdf. Cited in
17 Section 1.2 (pg.5).
- 18 12. N. R. C. Committee on Elementary Particle Physics in the 21st Century, *Revealing the
19 Hidden Nature of Space and Time: Charting the Course for Elementary Particle Physics*.
20 The National Academies Press, 2006. ISBN 0-309-66039-4. Cited in Section 1.2 (pg.5).
- 21 13. Neutrino Scientific Assessment Group, “Recommendations to the Department of Energy
22 and the National Science Foundation on a Future U.S. Program in Neutrino Oscillations.
23 Report to the Nuclear Science Advisory Committee and the High Energy Physics Advisory
1 Board.”. July, 2007. http://science.energy.gov/~/media/hep/pdf/files/pdfs/nusagfinalreportjuly13_2007.pdf. Cited in Section 1.2 (pg.5).
- 3 14. Particle Physics Project Prioritization Panel, “U.S. Particle Physics: Scientific
4 opportunities, a plan for the next ten years.”. May, 2008. http://science.energy.gov/~/media/hep/pdf/files/pdfs/p5_report_06022008.pdf.
5 Cited in Sections 1.2 (pg.5), 3.1 (pg.46), and 3.2 (pg.48).
- 7 15. Ad Hoc Committee to Assess the Science Proposed for a Deep Underground Science and
8 Engineering Laboratory (DUSEL); National Research Council, *An Assessment of the Deep
9 Underground Science and Engineering Laboratory*. The National Academies Press, 2012.
10 ISBN 978-0-309-21723-1. Cited in Section 1.2 (pg.5).
- 11 16. HEPAP Facilities Subpanel, “Major High Energy Physics Facilities 2014-2024. Input to the
12 prioritization of proposed scientific user facilities for the Office of Science.”. March, 2013.
13 http://science.energy.gov/~/media/hep/hepap/pdf/Reports/HEPAP_facilities_letter_report.pdf. Cited in Section 1.2 (pg.5).

- 15 17. CERN Council, “The European Strategy for Particle Physics, Update 2013.”.
16 CERN-Council-S/106, May, 2013.
17 <http://council.web.cern.ch/council/en/EuropeanStrategy/esc-e-106.pdf>.
18 Cited in Sections 1.2 (pg.5) and 1.2.3 (pg.7).
- 19 18. DOE Office of Science, Office of High Energy Physics, “Mission Need Statement for a
20 Long-Baseline Neutrino Experiment (LBNE),” DOE, LBNE-doc-6259, 2009. Cited in
21 Sections 1.2.1 (pg.6) and 3.1 (pg.47).
- 22 19. A. S. Kronfeld, R. S. Tschirhart, U. Al-Binni, W. Altmannshofer, C. Ankenbrandt, *et al.*,
23 “Project X: Physics Opportunities,” FERMILAB-TM-2557, BNL-101116-2013-BC-81834,
24 JLAB-ACP-13-1725, UASLP-IF-13-001, SLAC-R-1029, ANL-PHY-13-2, PNNL-22523,
25 LBNL-6334E, arXiv:1306.5009 [hep-ex], 2013. Cited in Section 1.2.1 (pg.6).
- 26 20. A. de Gouvea *et al.*, **Intensity Frontier Neutrino Working Group**, “Neutrinos,”
27 FERMILAB-CONF-13-479-E, arXiv:1310.4340 [hep-ex], 2013. Cited in
28 Sections 1.2.1 (pg.6) and 2.2 (pg.23).
- 29 21. K. Babu, E. Kearns, U. Al-Binni, S. Banerjee, D. Baxter, *et al.*, “Baryon Number
30 Violation,” arXiv:1311.5285 [hep-ph], 2013. Cited in Section 1.2.1 (pg.6).
- 31 22. Derwent, P. and others, “Proton Improvement Plan II,” Project X-doc-1232, November,
1 2013. Cited in Sections 1.2.1 (pg.6), 3.2 (pg.51), and 3.4 (pg.63).
- 2 23. S. Holmes, R. Alber, B. Chase, K. Gollwitzer, D. Johnson, *et al.*, “Project X: Accelerator
3 Reference Design,” FERMILAB-TM-2557, BNL-101116-2013-BC-81834,
4 JLAB-ACP-13-1725, PNNL-22523, SLAC-R-1020, UASLP-IF-13-001,
5 arXiv:1306.5022 [physics.acc-ph], 2013. Cited in Sections 1.2.1 (pg.6),
6 3.2 (pg.51), and 4.2.1 (pg.88).
- 7 24. “Final Report, Director’s Independent Conceptual Design and CD-1 Readiness Review of
8 the LBNE Project,” LBNE-doc-5788, March, 2012. Cited in Sections 1.2.2 (pg.7),
9 3.6 (pg.76), and 3.6.2 (pg.79).
- 10 25. Y. K. Kim *et al.*, “LBNE Reconfiguration: Steering Committee Report,” 2012.
11 http://www.fnal.gov/directorate/lbne_reconfiguration/index.shtml. Cited
12 in Sections 1.2.2 (pg.7), 1.3 (pg.9), 4.2.1 (pg.86), and 9.3 (pg.210).
- 13 26. “Department of Energy Review Committee Report on the Technical, Cost, Schedule, and
14 Management Review of the Long Baseline Neutrino Experiment (LBNE),” October, 2012.
15 http://www.fnal.gov/directorate/OPMO/Projects/LBNE/DOERev/2012/10_30/1210_LBNE_rpt.pdf. Cited in Section 1.2.2 (pg.7).
- 16 27. “Independent Cost Review Closeout for the Long Baseline Neutrino Experiment (LBNE)
17 Project,” LBNE-doc-6522, November, 2012. Cited in Section 1.2.2 (pg.7).
- 18 28. “Critical Decision 1 Approve Alternative Selection and Cost Range of the Long Baseline
19 Neutrino Experiment (LBNE) Project,” LBNE-doc-6681, December, 2012. Cited in
20 Section 1.2.2 (pg.7).
- 21 29. **LBNE Project Management Team**, “LBNE Conceptual Design Report, Volume 1: The
22 LBNE Project,” LBNE-doc-5235, 2012. Cited in Sections 1.2.2 (pg.7), 4.2.2 (pg.88),
23 4.3 (pg.92), 4.3 (pg.95), 4.6 (pg.124), and A (pg.213).

- 25 30. **LBNE Project Management Team**, “LBNE Conceptual Design Report, Volume 2: The
26 Beamline at the Near Site,” LBNE-doc-4317, 2012. Cited in Sections 1.2.2 (pg.7),
27 3.4 (pg.63), and 4.3 (pg.93).
- 28 31. **LBNE Project Management Team**, “LBNE Conceptual Design Report, Volume 3:
29 Detectors at the Near Site,” LBNE-doc-4724, 2012. Cited in Sections 1.2.2 (pg.7)
30 and 3.5 (pg.73).
- 31 32. **LBNE Project Management Team**, “LBNE Conceptual Design Report, Volume 4: The
32 Liquid Argon Detector at the Far Site,” LBNE-doc-4892, 2012. Cited in
33 Sections 1.2.2 (pg.7) and 3.6.1 (pg.77).
- 34 33. **LBNE Project Management Team**, “LBNE Conceptual Design Report, Volume 5:
35 Conventional Facilities at the Near Site (MI-10 Shallow),” LBNE-doc-4623, 2012. Cited
36 in Section 1.2.2 (pg.7).
- 37 34. **LBNE Project Management Team**, “LBNE Conceptual Design Report, Volume 6:
38 Conventional Facilities at the Far Site,” LBNE-doc-5017, 2012. Cited in
39 Section 1.2.2 (pg.7).
- 1 35. R. J. Wilson, “Long-Baseline Neutrino Experiment, presentation, November 2013,” 2013.
2 <https://indico.fnal.gov/getFile.py/access?contribId=25&sessionId=7&resId=0&materialId=slides&confId=7485>. Cited in Section 1.2.3 (pg.8).
- 4 36. Marx-Reichanadter Committee, “Department of Energy Office of Science Review of
5 Options for Underground Science.” June, 2011. http://science.energy.gov/~/media/np/pdf/review_of_underground_science_report_final.pdf. Cited in
6 Section 1.3 (pg.9).
- 8 37. Grannis, P. and Green, D. and Nishikawa, K. and Robertson, H. and Sadoulet, B. and Wark,
9 D., “The LBNE Science Capability Review,” LBNE-doc-5333, December, 2011. Cited in
10 Section 1.3 (pg.9).
- 11 38. M. Messier, **NOvA Collaboration**, “Extending the NOvA Physics Program,”
12 FERMILAB-CONF-13-308-E, arXiv:1308.0106 [hep-ex], 2013. Cited in
13 Sections 1.3.1 (pg.10) and 4.8 (pg.136).
- 14 39. P. Huber and J. Kopp, “Two experiments for the price of one? – The role of the second
15 oscillation maximum in long baseline neutrino experiments,” *JHEP* **1103** (2011) 013,
16 arXiv:1010.3706 [hep-ph]. Cited in Section 1.3.1 (pg.13).
- 17 40. E. Kearns, “Future Experiments for Proton Decay. Presentation at ISOUPS (International
18 Symposium: Opportunities in Underground Physics for Snowmass), Asilomar, May 2013,”
19 2013. Cited in Sections 1.3.2 (pg.13), 5.1 (pg.139), 5.1 (pg.140), and 5.2 (pg.141).
- 20 41. J. Strait, “Physics Research Goals After Reconfiguration,” LBNE-doc-3056, 2011. Cited
21 in Section 2.1 (pg.18).
- 22 42. R. Mohapatra, S. Antusch, K. Babu, G. Barenboim, M.-C. Chen, *et al.*, “Theory of
23 neutrinos: A White paper,” *Rept. Prog. Phys.* **70** (2007) 1757–1867,
24 arXiv:hep-ph/0510213 [hep-ph]. Cited in Sections 2.2 (pg.21) and 2.2 (pg.23).

- 25 43. G. Aad *et al.*, **ATLAS Collaboration**, “Observation of a new particle in the search for the
26 Standard Model Higgs boson with the ATLAS detector at the LHC,” *Phys.Lett.* **B716**
27 (2012) 1–29, arXiv:1207.7214 [hep-ex]. Cited in Section 2.2 (pg.21).
- 28 44. S. Chatrchyan *et al.*, **CMS Collaboration**, “Observation of a new boson at a mass of 125
29 GeV with the CMS experiment at the LHC,” *Phys.Lett.* **B716** (2012) 30–61,
30 arXiv:1207.7235 [hep-ex]. Cited in Section 2.2 (pg.21).
- 31 45. DNP/DPF/DAP/DPB Joint Study on the Future of Neutrino Physics, “The Neutrino
32 Matrix.” November, 2004. <http://www.aps.org/policy/reports/multidivisional/neutrino/upload/main.pdf>.
33 Cited in Section 2.2 (pg.22).
- 35 46. F. An *et al.*, **Daya Bay Collaboration**, “Improved Measurement of Electron Antineutrino
36 Disappearance at Daya Bay,” *Chin. Phys.* **C37** (2013) 011001, arXiv:1210.6327
1 [hep-ex]. Cited in Section 2.2 (pg.22).
- 2 47. A. Aguilar-Arevalo *et al.*, **LSND Collaboration**, “Evidence for neutrino oscillations from
3 the observation of anti-neutrino(electron) appearance in a anti-neutrino(muon) beam,”
4 *Phys.Rev.* **D64** (2001) 112007, arXiv:hep-ex/0104049 [hep-ex]. Cited in
5 Section 2.2 (pg.23).
- 6 48. A. Aguilar-Arevalo *et al.*, **MiniBooNE Collaboration**, “A Search for electron neutrino
7 appearance at the $\Delta m^2 \sim 1\text{eV}^2$ scale,” *Phys.Rev.Lett.* **98** (2007) 231801,
8 arXiv:0704.1500 [hep-ex]. Cited in Section 2.2 (pg.23).
- 9 49. A. Aguilar-Arevalo *et al.*, **MiniBooNE Collaboration**, “Improved Search for $\overline{\nu}_\mu \rightarrow \overline{\nu}_e$
10 Oscillations in the MiniBooNE Experiment,” *Phys.Rev.Lett.* **110** no. 16, (2013) 161801,
11 arXiv:1207.4809 [hep-ex]. Cited in Section 2.2 (pg.23).
- 12 50. G. Mention, M. Fechner, T. Lasserre, T. Mueller, D. Lhuillier, *et al.*, “The Reactor
1 Antineutrino Anomaly,” *Phys.Rev.* **D83** (2011) 073006, arXiv:1101.2755 [hep-ex].
2 Cited in Section 2.2 (pg.23).
- 3 51. S. F. King, A. Merle, S. Morisi, Y. Shimizu, and M. Tanimoto, “Neutrino Mass and
4 Mixing: from Theory to Experiment,” arXiv:1402.4271 [hep-ph], 2014. Cited in
5 Section 2.2 (pg.23).
- 6 52. P. Harrison, D. Perkins, and W. Scott, “Tri-bimaximal mixing and the neutrino oscillation
7 data,” *Phys.Lett.* **B530** (2002) 167, arXiv:hep-ph/0202074 [hep-ph]. Cited in
8 Section * (pg.23).
- 9 53. C. H. Albright and M.-C. Chen, “Model Predictions for Neutrino Oscillation Parameters,”
10 *Phys.Rev.* **D74** (2006) 113006, arXiv:hep-ph/0608137 [hep-ph]. Cited in
11 Section 2.2 (pg.23).
- 12 54. G. Fogli, E. Lisi, A. Marrone, D. Montanino, A. Palazzo, *et al.*, “Global analysis of
13 neutrino masses, mixings and phases: entering the era of leptonic CP violation searches,”
14 *Phys.Rev.* **D86** (2012) 013012, arXiv:1205.5254 [hep-ph]. Cited in Sections † (pg.24),
15 2.2.1 (pg.25), 4.3 (pg.92), 4.3 (pg.93), 4.3.2 (pg.110), and 4.4 (pg.117).
- 16 55. J. Beringer *et al.*, **Particle Data Group**, “Review of Particle Physics (RPP),” *Phys.Rev.*
17 **D86** (2012) 010001. Cited in Sections 2.2.1 (pg.25), 2.2.2 (pg.27), and 7.4.4 (pg.183).

- 18 56. C. Jarlskog, “A Basis Independent Formulation of the Connection Between Quark Mass
19 Matrices, CP Violation and Experiment,” *Z.Phys.* **C29** (1985) 491–497. Cited in
20 Section 2.2.1 (pg.24).
- 21 57. A. Meroni, S. Petcov, and M. Spinrath, “A SUSY SU(5)xT’ Unified Model of Flavour with
22 large θ_{13} ,” *Phys.Rev.* **D86** (2012) 113003, arXiv:1205.5241 [hep-ph]. Cited in
23 Section 2.2.1 (pg.25).
- 24 58. G.-J. Ding, S. F. King, and A. J. Stuart, “Generalised CP and A_4 Family Symmetry,” *JHEP*
25 **1312** (2013) 006, arXiv:1307.4212. Cited in Section 2.2.1 (pg.25).
- 26 59. C. Luhn, “Trimaximal TM₁ neutrino mixing in S_4 with spontaneous CP violation,”
27 *Nucl.Phys.* **B875** (2013) 80–100, arXiv:1306.2358 [hep-ph]. Cited in
28 Sections 2.2.1 (pg.25) and 2.2.6 (pg.35).
- 29 60. G.-J. Ding and Y.-L. Zhou, “Predicting Lepton Flavor Mixing from $\Delta(48)$ and Generalized
1 CP Symmetries,” arXiv:1312.5222 [hep-ph], 2013. Cited in Section 2.2.1 (pg.25).
- 2 61. S. Antusch, S. F. King, and M. Spinrath, “Spontaneous CP violation in $A_4 \times SU(5)$ with
3 Constrained Sequential Dominance 2,” *Phys.Rev.* **D87** no. 9, (2013) 096018,
1 arXiv:1301.6764 [hep-ph]. Cited in Section 2.2.1 (pg.25).
- 2 62. S. F. King, “A model of quark and lepton mixing,” *JHEP* **1401** (2014) 119,
3 arXiv:1311.3295 [hep-ph]. Cited in Section 2.2.1 (pg.25).
- 4 63. E. Kolb and M. Turner, *The Early Universe*. Westview Press, 1994. ISBN
5 978-0201626742. Cited in Section 2.2.1 (pg.25).
- 6 64. S. Weinberg, *Cosmology*. Oxford University Press, USA, first ed., April, 2008. ISBN
7 978-0198526827. Cited in Section 2.2.1 (pg.25).
- 8 65. G. Steigman, “Primordial Nucleosynthesis in the Precision Cosmology Era,”
9 *Ann.Rev.Nucl.Part.Sci.* **57** (2007) 463–491, arXiv:0712.1100 [astro-ph]. Cited in
10 Section 2.2.1 (pg.25).
- 11 66. M. Fukugita and T. Yanagida, “Baryogenesis Without Grand Unification,” *Phys.Lett.* **B174**
12 (1986) 45. Cited in Section 2.2.1 (pg.25).
- 13 67. T. Yanagida, “Horizontal Symmetry and Masses of Neutrinos,” *Prog.Theor.Phys.* **64** (1980)
14 1103. Cited in Sections 2.2.1 (pg.25), 7.7 (pg.187), and 9.2 (pg.209).
- 15 68. S. Pascoli, S. Petcov, and A. Riotto, “Leptogenesis and Low Energy CP Violation in
16 Neutrino Physics,” *Nucl.Phys.* **B774** (2007) 1–52, arXiv:hep-ph/0611338 [hep-ph].
17 Cited in Section 2.2.1 (pg.26).
- 18 69. F. Capozzi, G. Fogli, E. Lisi, A. Marrone, D. Montanino, *et al.*, “Status of three-neutrino
19 oscillation parameters, circa 2013,” arXiv:1312.2878 [hep-ph], 2013. Cited in
20 Sections 2.2.1 (pg.26), 4.3.1 (pg.99), 4.3.3 (pg.112), 4.4 (pg.115), and 9.2 (pg.208).
- 21 70. P. Adamson *et al.*, **MINOS Collaboration**, “Search for the disappearance of muon
22 antineutrinos in the NuMI neutrino beam,” *Phys.Rev.* **D84** (2011) 071103,
1 arXiv:1108.1509 [hep-ex]. Cited in Section 2.2.2 (pg.26).
- 2 71. S. Mikheev and A. Y. Smirnov, “Resonance Amplification of Oscillations in Matter and
3 Spectroscopy of Solar Neutrinos,” *Sov.J.Nucl.Phys.* **42** (1985) 913–917. Cited in
1 Section 2.2.2 (pg.27).

- 2 72. L. Wolfenstein, “Neutrino Oscillations in Matter,” *Phys.Rev.* **D17** (1978) 2369–2374. Cited
3 in Section 2.2.2 (pg.27).
- 4 73. G. Bellini *et al.*, **Borexino Collaboration**, “Measurement of the solar 8B neutrino rate
5 with a liquid scintillator target and 3 MeV energy threshold in the Borexino detector,”
6 *Phys.Rev.* **D82** (2010) 033006, arXiv:0808.2868 [astro-ph]. Cited in
7 Section 2.2.2 (pg.27).
- 8 74. G. Bellini, J. Benziger, D. Bick, S. Bonetti, G. Bonfini, *et al.*, “Precision measurement of
9 the 7Be solar neutrino interaction rate in Borexino,” *Phys.Rev.Lett.* **107** (2011) 141302,
10 arXiv:1104.1816 [hep-ex]. Cited in Section 2.2.2 (pg.27).
- 11 75. B. Aharmim *et al.*, **SNO Collaboration**, “Combined Analysis of all Three Phases of Solar
12 Neutrino Data from the Sudbury Neutrino Observatory,” *Phys.Rev.* **C88** (2013) 025501,
13 arXiv:1109.0763 [nucl-ex]. Cited in Section 2.2.2 (pg.27).
- 14 76. A. Renshaw *et al.*, **Super-Kamiokande Collaboration**, “First Indication of Terrestrial
15 Matter Effects on Solar Neutrino Oscillation,” arXiv:1312.5176 [hep-ex], 2013. Cited
16 in Sections 2.2.2 (pg.27) and 8.1 (pg.199).
- 17 77. M. Freund, “Analytic approximations for three neutrino oscillation parameters and
18 probabilities in matter,” *Phys.Rev.* **D64** (2001) 053003, arXiv:hep-ph/0103300
19 [hep-ph]. Cited in Section 2.2.2 (pg.27).
- 20 78. W. Marciano and Z. Parsa, “Intense neutrino beams and leptonic CP violation,”
21 *Nucl.Phys.Proc.Suppl.* **221** (2011) 166–172, arXiv:hep-ph/0610258 [hep-ph]. Cited
22 in Section 2.2.2 (pg.30).
- 23 79. B. Viren, “libnuosc++ - A library for calculating 3 neutrino oscillation probabilities.”
24 <https://github.com/brettviren/nuosc>. Cited in Section 2.2.3 (pg.30).
- 25 80. A. M. Dziewonski and D. L. Anderson, “Preliminary reference Earth model,” *Phys. Earth
26 Plan. Int.* **25** (1981) 297. Cited in Section 2.2.3 (pg.30).
- 27 81. J. Appel *et al.*, “Physics Working Group Report to the LBNE Reconfiguration Steering
28 Committee,” 2012. [http://www.fnal.gov/directorate/lbne_reconfiguration/
29 files/LBNE-Reconfiguration-PhysicsWG-Report-August2012.pdf](http://www.fnal.gov/directorate/lbne_reconfiguration/files/LBNE-Reconfiguration-PhysicsWG-Report-August2012.pdf). Cited in
30 Section 2.2.5 (pg.35).
- 31 82. R. Brun, F. Bruyant, M. Maire, A. McPherson, and P. Zanarini, “GEANT3,”
32 CERN-DD-EE-84-1, 1987. Cited in Section 2.2.5 (pg.33).
- 33 83. M. Bass *et al.*, **LBNE Collaboration**, “Baseline optimization for the measurement of CP
34 violation and mass hierarchy in a long-baseline neutrino oscillation experiment,”
35 FERMILAB-PUB-13-506-E, arXiv:1311.0212 [hep-ex], 2013. Cited in
1 Sections 2.2.5 (pg.35) and 3.1 (pg.47).
- 2 84. M. Raidal, “Relation between the neutrino and quark mixing angles and grand unification,”
3 *Phys.Rev.Lett.* **93** (2004) 161801, arXiv:hep-ph/0404046 [hep-ph]. Cited in
4 Section 2.2.6 (pg.35).
- 5 85. H. Minakata and A. Y. Smirnov, “Neutrino mixing and quark-lepton complementarity,”
6 *Phys.Rev.* **D70** (2004) 073009, arXiv:hep-ph/0405088 [hep-ph]. Cited in
7 Section 2.2.6 (pg.35).

- 8 86. A. Y. Smirnov, “Neutrino mass, mixing and discrete symmetries,” *J.Phys.Conf.Ser.* **447**
9 (2013) 012004, arXiv:1305.4827 [hep-ph]. Cited in Section 2.2.6 (pg.35).
10 87. J. Harada, “Non-maximal θ_{23} , large θ_{13} and tri-bimaximal θ_{12} via quark-lepton
11 complementarity at next-to-leading order,” *Europhys.Lett.* **103** (2013) 21001,
12 arXiv:1304.4526 [hep-ph]. Cited in Section 2.2.6 (pg.35).
13 88. B. Hu, “Trimaximal-Cabibbo neutrino mixing: A parametrization in terms of deviations
14 from tribimaximal mixing,” *Phys.Rev.* **D87** no. 5, (2013) 053011, arXiv:1212.4079
15 [hep-ph]. Cited in Section 2.2.6 (pg.35).
16 89. P. Ramond, “Fundamental Physics Underground. Presentation at ISOUPS (International
17 Symposium: Opportunities in Underground Physics for Snowmass), Asilomar, May 2013,”
18 2013. Cited in Section 2.2.6 (pg.35).
19 90. S. Antusch, C. Biggio, E. Fernandez-Martinez, M. Gavela, and J. Lopez-Pavon, “Unitarity
20 of the Leptonic Mixing Matrix,” *JHEP* **0610** (2006) 084, arXiv:hep-ph/0607020
21 [hep-ph]. Cited in Section 2.2.6 (pg.35).
22 91. X. Qian, C. Zhang, M. Diwan, and P. Vogel, “Unitarity Tests of the Neutrino Mixing
23 Matrix,” arXiv:1308.5700 [hep-ex], 2013. Cited in Sections 2.2.6 (pg.35)
24 and 2.2.6 (pg.36).
25 92. J. C. Pati and A. Salam, “Is Baryon Number Conserved?,” *Phys.Rev.Lett.* **31** (1973)
26 661–664. Cited in Section 2.3.1 (pg.38).
27 93. H. Georgi and S. Glashow, “Unity of All Elementary Particle Forces,” *Phys.Rev.Lett.* **32**
28 (1974) 438–441. Cited in Section 2.3.1 (pg.38).
29 94. S. Dimopoulos, S. Raby, and F. Wilczek, “Proton Decay in Supersymmetric Models,”
30 *Phys.Lett.* **B112** (1982) 133. Cited in Section 2.3.1 (pg.38).
31 95. P. Langacker, “Grand Unified Theories and Proton Decay,” *Phys.Rept.* **72** (1981) 185.
32 Cited in Section 2.3.1 (pg.38).
33 96. W. de Boer, “Grand unified theories and supersymmetry in particle physics and
34 cosmology,” *Prog.Part.Nucl.Phys.* **33** (1994) 201–302, arXiv:hep-ph/9402266
35 [hep-ph]. Cited in Section 2.3.1 (pg.38).
36 97. P. Nath and P. Fileviez Perez, “Proton stability in grand unified theories, in strings and in
37 branes,” *Phys.Rept.* **441** (2007) 191–317, arXiv:hep-ph/0601023 [hep-ph]. Cited in
1 Section 2.3.1 (pg.38).
2 98. S. Raby, T. Walker, K. Babu, H. Baer, A. Balantekin, *et al.*, “DUSEL Theory White Paper,”
3 SLAC-PUB-14734, FERMILAB-PUB-08-680-T, arXiv:0810.4551 [hep-ph], 2008.
4 Cited in Section 2.3.1 (pg.38).
5 99. G. Senjanovic, “Proton decay and grand unification,” *AIP Conf.Proc.* **1200** (2010)
6 131–141, arXiv:0912.5375 [hep-ph]. Cited in Section 2.3.1 (pg.38).
7 100. T. Li, D. V. Nanopoulos, and J. W. Walker, “Elements of F-ast Proton Decay,” *Nucl.Phys.*
8 **B846** (2011) 43–99, arXiv:1003.2570 [hep-ph]. Cited in Section 2.3.1 (pg.38).
9 101. E. Noether, “Invariant Variation Problems,” *Gott.Nachr.* **1918** (1918) 235–257,
10 arXiv:physics/0503066 [physics]. Cited in Section 2.3.1 (pg.39).

102. H. Nishino *et al.*, **Super-Kamiokande Collaboration**, “Search for Nucleon Decay into Charged Anti-lepton plus Meson in Super-Kamiokande I and II,” *Phys.Rev.* **D85** (2012) 112001, arXiv:1203.4030 [hep-ex]. Cited in Section 2.3.2 (pg.40).
103. R. Bionta, G. Blewitt, C. Bratton, D. Casper, A. Ciocio, *et al.*, “Observation of a Neutrino Burst in Coincidence with Supernova SN 1987a in the Large Magellanic Cloud,” *Phys.Rev.Lett.* **58** (1987) 1494. Cited in Sections 2.4 (pg.42) and 6.1 (pg.151).
104. K. Hirata *et al.*, **KAMIOKANDE-II Collaboration**, “Observation of a Neutrino Burst from the Supernova SN 1987a,” *Phys.Rev.Lett.* **58** (1987) 1490–1493. Cited in Sections 2.4 (pg.42) and 6.1 (pg.151).
105. E. Alekseev, L. Alekseeva, V. Volchenko, and I. Krivosheina, “Possible Detection of a Neutrino Signal on 23 February 1987 at the Baksan Underground Scintillation Telescope of the Institute of Nuclear Research,” *JETP Lett.* **45** (1987) 589–592. Cited in Section 2.4 (pg.42).
106. K. Scholberg, “Supernova neutrino detection,” *Nucl.Phys.Proc.Suppl.* **221** (2011) 248–253, arXiv:astro-ph/0701081 [astro-ph]. Cited in Sections 2.4 (pg.42) and 2.4 (pg.44).
107. A. Dighe, “Physics potential of future supernova neutrino observations,” *J.Phys.Conf.Ser.* **136** (2008) 022041, arXiv:0809.2977 [hep-ph]. Cited in Section 2.4 (pg.42).
108. G. A. Tammann, W. Loeffler, and A. Schroder, “The Galactic supernova rate,” *Astrophys. J. Suppl.* **92** (1994) 487–493. Cited in Section 2.4 (pg.42).
109. E. Cappellaro, R. Evans, and M. Turatto, “A new determination of supernova rates and a comparison with indicators for galactic star formation,” *Astron.Astrophys.* **351** (1999) 459, arXiv:astro-ph/9904225 [astro-ph]. Cited in Section 2.4 (pg.42).
110. G. Pagliaroli, F. Vissani, E. Coccia, and W. Fulgione, “Neutrinos from Supernovae as a Trigger for Gravitational Wave Search,” *Phys. Rev. Lett.* **103** (2009) 031102, arXiv:0903.1191 [hep-ph]. Cited in Section 2.4 (pg.43).
111. C. Ott, E. O’Connor, S. Gossan, E. AbdiKamalov, U. Gamma, *et al.*, “Core-Collapse Supernovae, Neutrinos, and Gravitational Waves,” *Nucl.Phys.Proc.Suppl.* **235-236** (2013) 381–387, arXiv:1212.4250 [astro-ph.HE]. Cited in Section 2.4 (pg.43).
112. A. Mirizzi, G. Raffelt, and P. Serpico, “Earth matter effects in supernova neutrinos: Optimal detector locations,” *JCAP* **0605** (2006) 012, arXiv:astro-ph/0604300 [astro-ph]. Cited in Sections 2.4 (pg.43) and 2.4 (pg.44).
113. S. Choubey, B. Dasgupta, A. Dighe, and A. Mirizzi, “Signatures of collective and matter effects on supernova neutrinos at large detectors,” arXiv:1008.0308 [hep-ph], 2010. Cited in Section 2.4 (pg.43).
114. G. G. Raffelt, “Astrophysical axion bounds: An Update,” arXiv:astro-ph/9707268 [astro-ph], 1997. Cited in Section 2.4 (pg.43).
115. S. Hannestad and G. Raffelt, “New supernova limit on large extra dimensions,” *Phys.Rev.Lett.* **87** (2001) 051301, arXiv:hep-ph/0103201 [hep-ph]. Cited in Section 2.4 (pg.43).
116. P. Antonioli *et al.*, “Snews: The supernova early warning system,” *New J. Phys.* **6** (2004) 114, astro-ph/0406214. Cited in Sections 2.4 (pg.44) and 6.1 (pg.153).

- 25 117. K. Scholberg, “The SuperNova Early Warning System,” *Astron. Nachr.* **329** (2008)
26 337–339, arXiv:0803.0531 [astro-ph]. Cited in Sections 2.4 (pg.44)
27 and 6.1 (pg.153).
- 28 118. K. Scholberg, “Future supernova neutrino detectors,” *J.Phys.Conf.Ser.* **203** (2010) 012079.
29 Cited in Section 2.4 (pg.44).
- 30 119. “Sanford Underground Research Facility.” <http://www.sanfordlab.org>. Cited in
31 Section 3.3 (pg.54).
- 32 120. B. Cleveland, T. Daily, R. Davis Jr., J. R. Distel, K. Lande, *et al.*, “Measurement of the
33 solar electron neutrino flux with the Homestake chlorine detector,” *Astrophys.J.* **496** (1998)
34 505–526. Cited in Sections 3.3 (pg.54) and 8.1 (pg.195).
- 35 121. F. Gray, C. Ruybal, J. Totushek, D.-M. Mei, K. Thomas, *et al.*, “Cosmic Ray Muon Flux at
36 the Sanford Underground Laboratory at Homestake,” *Nucl.Instrum.Meth.* **A638** (2011)
1 63–66, arXiv:1007.1921 [nucl-ex]. Cited in Section 3.3 (pg.58).
- 2 122. W. Roggenthen and A. Smith, “U, Th, K contents of materials associated with the
3 Homestake DUSEL site, Lead, South Dakota,” *Private Communication*. Cited in
4 Section 3.3 (pg.59).
- 5 123. D. Akerib *et al.*, **LUX Collaboration**, “First results from the LUX dark matter experiment
6 at the Sanford Underground Research Facility,” arXiv:1310.8214 [astro-ph.CO],
7 2013. Cited in Section 3.3 (pg.59).
- 8 124. M. Bishai and Y. Lu, “Conceptual Designs for a Wide-Band Low-Energy Neutrino Beam
9 Target,” LBNE-doc-3151, November, 2010.
- 10 125. B. Lundberg, “A beginner guide to horn design and history of LBNE horn design,”
11 LBNE-doc-8398, November, 2014.
- 12 126. D. Ayres *et al.*, **NOvA Collaboration**, “The NOvA Technical Design Report,”
13 FERMILAB-DESIGN-2007-01, 2007.
14 <http://lss.fnal.gov/archive/design/fermilab-design-2007-01.pdf>. Cited in
15 Sections 3.4 (pg.63), 4.2.1 (pg.88), 7.4.4 (pg.183), and 7.6 (pg.185).
- 16 127. E. Worcester, “Potential Sensitivity Improvements with 10 kT LBNE,” LBNE-doc-6599,
17 2012. Cited in Section 3.4 (pg.69).
- 18 128. S. Mishra, R. Petti, and C. Rosenfeld, “A High Resolution Neutrino Experiment in a
19 Magnetic Field for Project-X at Fermilab,” *PoS NUFACt08* (2008) 069,
20 arXiv:0812.4527 [hep-ex]. Cited in Section 3.5 (pg.71).
- 21 129. B. Choudhary *et al.*, **Indian Institutions and Fermilab Collaboration**, “LBNE-India
22 Detailed Project Report (DPR) submitted to DAE, India,” LBNE-doc-6704, 2012. Cited in
23 Sections 3.5 (pg.73), 3.5 (pg.74), and 7 (pg.163).
- 24 130. P. Huber, M. Lindner, and W. Winter, “Simulation of long-baseline neutrino oscillation
25 experiments with GLoBES (General Long Baseline Experiment Simulator),”
26 *Comput.Phys.Commun.* **167** (2005) 195, arXiv:hep-ph/0407333 [hep-ph]. Cited in
27 Sections 4.2 (pg.85), 4.2.1 (pg.86), 4.2.2 (pg.88), and A.3 (pg.225).

28. 131. P. Huber, J. Kopp, M. Lindner, M. Rolinec, and W. Winter, “New features in the simulation
29. of neutrino oscillation experiments with GLoBES 3.0: General Long Baseline Experiment
30. Simulator,” *Comput.Phys.Commun.* **177** (2007) 432–438, arXiv:hep-ph/0701187
31. [hep-ph]. Cited in Sections 4.2 (pg.85) and 4.2.2 (pg.88).
32. 132. S. Agostinelli *et al.*, **GEANT4**, “GEANT4: A simulation toolkit,” *Nucl. Instrum. Meth.*
33. **A506** (2003) 250–303. Cited in Sections 4.2.1 (pg.85), 6.2 (pg.154), and A.1.1 (pg.213).
34. 133. C. Andreopoulos, **GENIE Collaboration**, “The GENIE neutrino Monte Carlo generator,”
35. *Acta Phys.Polon.* **B40** (2009) 2461–2475. Cited in Sections 4.2.1 (pg.88), 4.6 (pg.122),
1 and A.1.1 (pg.216).
- 2 134. K. Abe *et al.*, **T2K Collaboration**, “The T2K Experiment,” *Nucl.Instrum.Meth.* **A659**
3 (2011) 106–135, arXiv:1106.1238 [physics.ins-det]. Cited in
4 Sections 4.2.1 (pg.88), 7.4.4 (pg.183), and 7.6 (pg.185).
- 5 135. **NuMI-MINOS**. <http://www-numi.fnal.gov/>. Cited in Section 4.2.1 (pg.88).
- 6 136. A. Rubbia, “LAGUNA-LBNO: Design of an underground neutrino observatory coupled to
7 long baseline neutrino beams from CERN,” *J.Phys.Conf.Ser.* **408** (2013) 012006. Cited in
8 Section 4.2.1 (pg.88).
- 9 137. J.-P. Delahaye, C. Ankenbrandt, A. Bogacz, S. Brice, A. Bross, *et al.*, “Enabling Intensity
10 and Energy Frontier Science with a Muon Accelerator Facility in the U.S.: A White Paper
11 Submitted to the 2013 U.S. Community Summer Study of the Division of Particles and
12 Fields of the American Physical Society,” FERMILAB-CONF-13-307-APC,
1 arXiv:1308.0494 [physics.acc-ph], 2013. Cited in Section 4.2.1 (pg.88).
- 2 138. A. Longhin, “Optimization of neutrino beams for underground sites in Europe,”
3 arXiv:1206.4294 [physics.ins-det], 2012. Cited in Section 4.2.1 (pg.88).
- 4 139. S. Amoruso *et al.*, **ICARUS Collaboration**, “Measurement of the mu decay spectrum
5 with the ICARUS liquid argon TPC,” *Eur.Phys.J.* **C33** (2004) 233–241,
6 arXiv:hep-ex/0311040 [hep-ex]. Cited in Sections 4.2.2 (pg.88), 4.6 (pg.124),
7 and 6.2 (pg.154).
- 8 140. T2K Collaboration, “A Proposal for a Detector 2km Away from the T2K Neutrino
9 Source.”. 2005. <http://www.phy.duke.edu/~cwalter/nusag-members/2km-proposal-05-05-30.pdf>.
10 Cited in Section 4.2.2 (pg.89).
- 11 141. A. Ankowski *et al.*, **ICARUS Collaboration**, “Measurement of through-going particle
12 momentum by means of multiple scattering with the ICARUS T600 TPC,” *Eur.Phys.J.* **C48**
13 (2006) 667–676, arXiv:hep-ex/0606006 [hep-ex]. Cited in Section 4.2.2 (pg.89).
142. 142. F. An *et al.*, **Daya Bay Collaboration**, “Spectral measurement of electron antineutrino
15 oscillation amplitude and frequency at Daya Bay,” arXiv:1310.6732 [hep-ex], 2013.
16 Cited in Sections 4.3 (pg.93) and 4.5 (pg.119).
- 17 143. P. Adamson *et al.*, **MINOS Collaboration**, “Electron neutrino and antineutrino
18 appearance in the full MINOS data sample,” *Phys.Rev.Lett.* **110** no. 17, (2013) 171801,
19 arXiv:1301.4581 [hep-ex]. Cited in Sections 4.3 (pg.93), 4.3.2 (pg.103),
20 and 4.3.2 (pg.108).

- 9 144. M. J. Murtagh, **E734 Collaboration**, “A Search for muon-neutrino to electron-neutrino
10 oscillations using the E734 detector,” BNL-39667, 1987.
- 11 145. R. Seto, “BNL E776: A Search for neutrino oscillations,” *AIP Conf.Proc.* **176** (1988)
12 957–963.
- 13 146. L. Borodovsky, C. Chi, Y. Ho, N. Kondakis, W.-Y. Lee, *et al.*, “Search for muon-neutrino
14 oscillations muon-neutrino to electron-neutrino (anti-muon-neutrino to
15 anti-electron-neutrino in a wide band neutrino beam,” *Phys.Rev.Lett.* **68** (1992) 274–277.
- 16 147. P. Astier *et al.*, **NOMAD Collaboration**, “Search for nu(mu) → nu(e) oscillations in the
17 NOMAD experiment,” *Phys.Lett.* **B570** (2003) 19–31, arXiv:hep-ex/0306037
18 [hep-ex].
- 19 148. A. Aguilar-Arevalo *et al.*, **MiniBooNE Collaboration**, “Unexplained Excess of
20 Electron-Like Events From a 1-GeV Neutrino Beam,” *Phys.Rev.Lett.* **102** (2009) 101802,
21 arXiv:0812.2243 [hep-ex]. Cited in Section 7.7 (pg.190).
- 22 149. K. Abe *et al.*, **T2K Collaboration**, “Observation of Electron Neutrino Appearance in a
23 Muon Neutrino Beam,” arXiv:1311.4750 [hep-ex], 2013. Cited in
24 Section 4.3.2 (pg.103).
- 25 150. X. Qian, A. Tan, W. Wang, J. Ling, R. McKeown, *et al.*, “Statistical Evaluation of
26 Experimental Determinations of Neutrino Mass Hierarchy,” *Phys.Rev.* **D86** (2012) 113011,
27 arXiv:1210.3651 [hep-ph]. Cited in Sections 4.3.1 (pg.96), 4.3.1 (pg.97),
28 4.3.1 (pg.99), and 4.3.1 (pg.100).
- 29 151. M. Blennow, P. Coloma, P. Huber, and T. Schwetz, “Quantifying the sensitivity of
30 oscillation experiments to the neutrino mass ordering,” arXiv:1311.1822 [hep-ph],
31 2013. Cited in Sections 4.3.1 (pg.97), 4.3.1 (pg.98), 4.3.1 (pg.99), 4.3.1 (pg.100),
32 and 4.8 (pg.137).
- 33 152. R. Cousins, “Private communication,” 2013. Cited in Section 4.3.1 (pg.99).
- 34 153. R. Cousins, J. Mumford, J. Tucker, and V. Valuev, “Spin discrimination of new heavy
1 resonances at the LHC,” *JHEP* **0511** (2005) 046. Cited in Section 4.3.1 (pg.99).
- 2 154. P. Adamson *et al.*, **MINOS Collaboration**, “Improved search for muon-neutrino to
3 electron-neutrino oscillations in MINOS,” *Phys.Rev.Lett.* **107** (2011) 181802,
4 arXiv:1108.0015 [hep-ex]. Cited in Section 4.3.2 (pg.103).
- 5 155. P. Adamson *et al.*, **MINOS Collaboration**, “Neutrino and Antineutrino Inclusive
6 Charged-current Cross Section Measurements with the MINOS Near Detector,” *Phys.Rev.*
7 **D81** (2010) 072002, arXiv:0910.2201 [hep-ex]. Cited in Sections 4.3.2 (pg.103)
8 and 7.1.8 (pg.169).
- 9 156. Q. Wu *et al.*, **NOMAD Collaboration**, “A Precise measurement of the muon
10 neutrino-nucleon inclusive charged current cross-section off an isoscalar target in the
11 energy range $2.5 < E(\nu) < 40$ -GeV by NOMAD,” *Phys.Lett.* **B660** (2008) 19–25,
12 arXiv:0711.1183 [hep-ex]. Cited in Sections 4.3.2 (pg.103), 7.1.8 (pg.169),
13 and 7.4.4 (pg.183).

14. 157. V. Lyubushkin *et al.*, **NOMAD Collaboration**, “A Study of quasi-elastic muon neutrino
1 and antineutrino scattering in the NOMAD experiment,” *Eur.Phys.J.* **C63** (2009) 355–381,
2 arXiv:0812.4543 [hep-ex]. Cited in Sections 4.3.2 (pg.103) and 7.1.8 (pg.169).
3. 158. A. Bodek, U. Sarica, K. Kuzmin, and V. Naumov, “Extraction of Neutrino Flux with the
4 Low ν Method at MiniBooNE Energies,” *AIP Conf.Proc.* **1560** (2013) 193–197,
5 arXiv:1207.1247 [hep-ex]. Cited in Section 4.3.2 (pg.103).
6. 159. P. Adamson *et al.*, **MINOS Collaboration**, “A Study of Muon Neutrino Disappearance
7 Using the Fermilab Main Injector Neutrino Beam,” *Phys.Rev.* **D77** (2008) 072002,
8 arXiv:0711.0769 [hep-ex]. Cited in Section 4.3.2 (pg.103).
9. 160. M. Bishai, “Determining the Neutrino Flux from Accelerator Neutrino Beams,”
10 *Nucl.Phys.Proc.Suppl.* **229-232** (2012) 210–214. Cited in Section 4.3.2 (pg.103).
11. 161. B. Osmanov, **MINERvA Collaboration**, “MINERvA Detector: Description and
12 Performance,” arXiv:1109.2855 [physics.ins-det], 2011. Cited in
13 Sections 4.3.2 (pg.104), 7.4.4 (pg.182), 7.4.4 (pg.183), and 7.6 (pg.185).
14. 162. A. Korzenev, **NA61/SHINE**, “Hadron production measurement from NA61/SHINE,”
15 arXiv:1311.5719 [nucl-ex], 2013. Cited in Sections 4.3.2 (pg.104)
1 and 7.1.2 (pg.166).
2. 163. P. Adamson *et al.*, **MINOS Collaboration**, “Measurement of the neutrino mass splitting
3 and flavor mixing by MINOS,” *Phys.Rev.Lett.* **106** (2011) 181801, arXiv:1103.0340
4 [hep-ex]. Cited in Sections 4.3.2 (pg.105) and 4.5 (pg.120).
5. 164. T. Yang, **ArgoNeuT Collaboration**, “New Results from ArgoNeuT,”
6 FERMILAB-CONF-13-510-E, arXiv:1311.2096 [hep-ex], 2013. Cited in
7 Section 4.3.2 (pg.107).
8. 165. M. Day and K. S. McFarland, “Differences in Quasi-Elastic Cross-Sections of Muon and
9 Electron Neutrinos,” *Phys.Rev.* **D86** (2012) 053003, arXiv:1206.6745 [hep-ph]. Cited
10 in Section 4.3.2 (pg.108).
11. 166. K. Abe *et al.*, **Super-Kamiokande Collaboration**, “Search for Differences in Oscillation
12 Parameters for Atmospheric Neutrinos and Antineutrinos at Super-Kamiokande,”
13 *Phys.Rev.Lett.* **107** (2011) 241801, arXiv:1109.1621 [hep-ex]. Cited in
14 Section 4.4 (pg.115).
15. 167. P. Adamson *et al.*, **MINOS Collaboration**, “Measurement of Neutrino and Antineutrino
16 Oscillations Using Beam and Atmospheric Data in MINOS,” *Phys.Rev.Lett.* **110** (2013)
1 251801, arXiv:1304.6335 [hep-ex]. Cited in Section 4.6 (pg.122).
2. 168. V. Agrawal, T. Gaisser, P. Lipari, and T. Stanev, “Atmospheric neutrino flux above 1-GeV,”
3 *Phys.Rev.* **D53** (1996) 1314–1323, arXiv:hep-ph/9509423 [hep-ph]. Cited in
4 Section 4.6 (pg.122).
5. 169. A. Ankowski *et al.*, “Energy reconstruction of electromagnetic showers from pi0 decays
6 with the icarus t600 liquid argon tpc,” *Acta Physica Polonica B* **41** no. 1, (2010) 103,
7 arXiv:0812.2373 [hep-ex]. Cited in Section 4.6 (pg.124).

- 8 170. F. Arneodo *et al.*, **The ICARUS-Milano Collaboration**, “Performance of a liquid argon
9 time projection chamber exposed to the cern west area neutrino facility neutrino beam,”
10 *Phys. Rev. D* **74** (Dec, 2006) 112001.
11 <http://link.aps.org/doi/10.1103/PhysRevD.74.112001>. Cited in
12 Section 4.6 (pg.124).
- 13 171. C. Rubbia *et al.*, “Underground operation of the ICARUS T600 LAr-TPC: first results,”
14 *JINST* **6** (2011) P07011, arXiv:1106.0975 [hep-ex]. Cited in Section 4.6 (pg.124).
- 15 172. S. Davidson, C. Pena-Garay, N. Rius, and A. Santamaria, “Present and future bounds on
16 nonstandard neutrino interactions,” *JHEP* **0303** (2003) 011, arXiv:hep-ph/0302093
17 [hep-ph]. Cited in Section 4.7.1 (pg.132).
- 18 173. M. Gonzalez-Garcia and M. Maltoni, “Phenomenology with Massive Neutrinos,”
19 *Phys.Rept.* **460** (2008) 1–129, arXiv:0704.1800 [hep-ph]. Cited in
20 Section 4.7.1 (pg.132).
- 21 174. C. Biggio, M. Blennow, and E. Fernandez-Martinez, “General bounds on non-standard
22 neutrino interactions,” *JHEP* **0908** (2009) 090, arXiv:0907.0097 [hep-ph]. Cited in
23 Section 4.7.1 (pg.132).
- 24 175. H. Davoudiasl, H.-S. Lee, and W. J. Marciano, “Long-Range Lepton Flavor Interactions
25 and Neutrino Oscillations,” *Phys.Rev.* **D84** (2011) 013009, arXiv:1102.5352 [hep-ph].
26 Cited in Section 4.7.2 (pg.132).
- 27 176. P. Adamson *et al.*, **MINOS Collaboration**, “Search for sterile neutrino mixing in the
28 MINOS long baseline experiment,” *Phys.Rev.* **D81** (2010) 052004, arXiv:1001.0336
1 [hep-ex]. Cited in Section 4.7.3 (pg.134).
- 2 177. P. Machado, H. Nunokawa, F. P. d. Santos, and R. Z. Funchal, “Large Extra Dimensions
3 and Neutrino Oscillations,” arXiv:1110.1465 [hep-ph], 2011. Cited in
4 Section 4.7.4 (pg.135).
- 5 178. P. Coloma, P. Huber, J. Kopp, and W. Winter, “Systematic uncertainties in long-baseline
6 neutrino oscillations for large θ_{13} ,” *Phys.Rev.* **D87** no. 3, (2013) 033004,
7 arXiv:1209.5973 [hep-ph]. Cited in Section 4.8 (pg.135).
- 8 179. K. Abe, T. Abe, H. Aihara, Y. Fukuda, Y. Hayato, *et al.*, “Letter of Intent: The
9 Hyper-Kamiokande Experiment — Detector Design and Physics Potential —,”
10 arXiv:1109.3262 [hep-ex], 2011. Cited in Section 4.8 (pg.135).
- 11 180. A. Stahl, C. Wiebusch, A. Guler, M. Kamiscioglu, R. Sever, *et al.*, “Expression of Interest
12 for a very long baseline neutrino oscillation experiment (LBNO),” CERN-SPSC-2012-021,
13 SPSC-EOI-007, 2012. Cited in Section 4.8 (pg.135).
- 14 181. M. Apollonio, A. Bross, J. Kopp, and K. Long, **IDS-NF Collaboration**, “The
15 International Design Study for the Neutrino Factory,” *Nucl.Phys.Proc.Suppl.* **229-232**
16 (2012) 515. Cited in Section 4.8 (pg.135).
- 17 182. E. Christensen, P. Coloma, and P. Huber, “Physics Performance of a Low-Luminosity Low
18 Energy Neutrino Factory,” arXiv:1301.7727 [hep-ph], 2013. Cited in
19 Section 4.8 (pg.136).

- 20 183. E. Kearns *et al.*, **Hyper-Kamiokande Working Group**, “Hyper-Kamiokande Physics
21 Opportunities,” arXiv:1309.0184 [hep-ex], 2013. Cited in Section 4.8 (pg.136).
- 22 184. S. Agarwalla *et al.*, **LAGUNA-LBNO Collaboration**, “The mass-hierarchy and
23 CP-violation discovery reach of the LBNO long-baseline neutrino experiment,”
24 arXiv:1312.6520 [hep-ph], 2013. Cited in Section 4.8 (pg.136).
- 25 185. M. Bishai, M. Diwan, S. Kettell, J. Stewart, B. Viren, *et al.*, “Precision Neutrino
26 Oscillation Measurements using Simultaneous High-Power, Low-Energy Project-X
27 Beams,” BNL-101234-2013-CP, FERMILAB-FN-0962, arXiv:1307.0807 [hep-ex],
28 2013. Cited in Section 4.8 (pg.137).
- 29 186. J. L. Raaf, **Super-Kamiokande Collaboration**, “Recent Nucleon Decay Results from
30 Super-Kamiokande,” *Nucl.Phys.Proc.Suppl.* **229-232** (2012) 559. Cited in
1 Section 5.1 (pg.139).
- 2 187. A. Bueno, Z. Dai, Y. Ge, M. Laffranchi, A. Melgarejo, *et al.*, “Nucleon decay searches with
3 large liquid argon TPC detectors at shallow depths: Atmospheric neutrinos and cosmogenic
4 backgrounds,” *JHEP* **0704** (2007) 041, arXiv:hep-ph/0701101 [hep-ph]. Cited in
5 Sections 5.1 (pg.140), 5.2 (pg.140), 5.3.1 (pg.144), 5.3.1 (pg.145), and 5.3.2 (pg.145).
- 6 188. D. Stefan and A. M. Ankowski, “Nuclear effects in proton decay,” *Acta Phys.Polon.* **B40**
7 (2009) 671–674, arXiv:0811.1892 [nucl-th]. Cited in Section 5.2 (pg.141).
- 8 189. S. Amerio *et al.*, **ICARUS Collaboration**, “Design, construction and tests of the ICARUS
9 T600 detector,” *Nucl.Instrum.Meth.* **A527** (2004) 329–410. Cited in Section 5.2 (pg.141).
- 10 190. M. Antonello, B. Baibussinov, P. Benetti, E. Calligarich, N. Canci, *et al.*, “Precise 3D track
11 reconstruction algorithm for the ICARUS T600 liquid argon time projection chamber
12 detector,” *Adv.High Energy Phys.* **2013** (2013) 260820, arXiv:1210.5089
13 [physics.ins-det]. Cited in Sections 5.2 (pg.142) and 5.3.2 (pg.148).
- 1 191. A. Bernstein, M. Bishai, E. Blucher, D. B. Cline, M. V. Diwan, *et al.*, “Report on the Depth
2 Requirements for a Massive Detector at Homestake,” FERMILAB-TM-2424-E,
3 BNL-81896-2008-IR, LBNL-1348E, arXiv:0907.4183 [hep-ex], 2009. Cited in
4 Section 5.3.1 (pg.144).
- 5 192. V. Kudryavtsev *et al.*, “Cosmic rays and cosmogenics. report to the lbne collaboration.”,
6 LBNE-doc-5904, 2012. Cited in Section 5.3.1 (pg.144).
- 1 193. K. Kobayashi *et al.*, **Super-Kamiokande Collaboration**, “Search for nucleon decay via
2 modes favored by supersymmetric grand unification models in Super-Kamiokande-I,”
3 *Phys.Rev.* **D72** (2005) 052007, arXiv:hep-ex/0502026 [hep-ex]. Cited in
4 Section 5.3.2 (pg.146).
- 5 194. H. Gallagher, “Private communication.”. Cited in Section 5.3.2 (pg.148).
- 6 195. H.-T. Janka, “Explosion Mechanisms of Core-Collapse Supernovae,”
7 *Ann.Rev.Nucl.Part.Sci.* **62** (2012) 407–451, arXiv:1206.2503 [astro-ph.SR]. Cited in
8 Section 6.1 (pg.151).
- 9 196. T. Fischer, S. Whitehouse, A. Mezzacappa, F.-K. Thielemann, and M. Liebendorfer,
10 “Protoneutron star evolution and the neutrino driven wind in general relativistic neutrino

- radiation hydrodynamics simulations," *Astron.Astrophys.* **517** (2010) A80, arXiv:0908.1871 [astro-ph.HE]. Cited in Section 6.1 (pg.152).
197. M. Wurm *et al.*, **LENA Collaboration**, "The next-generation liquid-scintillator neutrino observatory LENA," *Astropart.Phys.* **35** (2012) 685–732, arXiv:1104.5620 [astro-ph.IM]. Cited in Section 6.1 (pg.152).
198. H. Minakata, H. Nunokawa, R. Tomas, and J. W. Valle, "Parameter Degeneracy in Flavor-Dependent Reconstruction of Supernova Neutrino Fluxes," *JCAP* **0812** (2008) 006, arXiv:0802.1489 [hep-ph]. Cited in Section 6.1 (pg.152).
199. I. Tamborra, B. Muller, L. Hudepohl, H.-T. Janka, and G. Raffelt, "High-resolution supernova neutrino spectra represented by a simple fit," *Phys.Rev.* **D86** (2012) 125031, arXiv:1211.3920 [astro-ph.SR]. Cited in Section 6.1 (pg.152).
200. H. Duan, G. M. Fuller, and Y.-Z. Qian, "Collective neutrino flavor transformation in supernovae," *Phys.Rev.* **D74** (2006) 123004, arXiv:astro-ph/0511275 [astro-ph]. Cited in Section 6.1 (pg.152).
201. G. L. Fogli, E. Lisi, A. Marrone, and A. Mirizzi, "Collective neutrino flavor transitions in supernovae and the role of trajectory averaging," *JCAP* **0712** (2007) 010, arXiv:0707.1998 [hep-ph]. Cited in Section 6.1 (pg.152).
202. G. G. Raffelt and A. Y. Smirnov, "Self-induced spectral splits in supernova neutrino fluxes," *Phys.Rev.* **D76** (2007) 081301, arXiv:0705.1830 [hep-ph]. Cited in Section 6.1 (pg.152).
203. G. G. Raffelt and A. Y. Smirnov, "Adiabaticity and spectral splits in collective neutrino transformations," *Phys.Rev.* **D76** (2007) 125008, arXiv:0709.4641 [hep-ph]. Cited in Section 6.1 (pg.152).
204. A. Esteban-Pretel, A. Mirizzi, S. Pastor, R. Tomas, G. Raffelt, *et al.*, "Role of dense matter in collective supernova neutrino transformations," *Phys.Rev.* **D78** (2008) 085012, arXiv:0807.0659 [astro-ph]. Cited in Section 6.1 (pg.152).
205. H. Duan and J. P. Kneller, "Neutrino flavour transformation in supernovae," *J.Phys.G* **G36** (2009) 113201, arXiv:0904.0974 [astro-ph.HE]. Cited in Section 6.1 (pg.152).
206. B. Dasgupta, A. Dighe, G. G. Raffelt, and A. Y. Smirnov, "Multiple Spectral Splits of Supernova Neutrinos," *Phys.Rev.Lett.* **103** (2009) 051105, arXiv:0904.3542 [hep-ph]. Cited in Section 6.1 (pg.152).
207. H. Duan, G. M. Fuller, and Y.-Z. Qian, "Collective Neutrino Oscillations," *Ann.Rev.Nucl.Part.Sci.* **60** (2010) 569–594, arXiv:1001.2799 [hep-ph]. Cited in Section 6.1 (pg.152).
208. H. Duan and A. Friedland, "Self-induced suppression of collective neutrino oscillations in a supernova," *Phys.Rev.Lett.* **106** (2011) 091101, arXiv:1006.2359 [hep-ph]. Cited in Sections 6.1 (pg.152) and 6.2 (pg.155).
209. J. F. Cherry, J. Carlson, A. Friedland, G. M. Fuller, and A. Vlasenko, "Halo Modification of a Supernova Neutronization Neutrino Burst," *Phys.Rev.* **D87** (2013) 085037, arXiv:1302.1159 [astro-ph.HE]. Cited in Section 6.1 (pg.153).

- 8 210. J. F. Beacom, R. Boyd, and A. Mezzacappa, “Black hole formation in core collapse
 9 supernovae and time-of-flight measurements of the neutrino masses,” *Phys.Rev.* **D63**
 1 (2001) 073011, arXiv:astro-ph/0010398 [astro-ph]. Cited in Section 6.1 (pg.153).
- 1 211. T. Fischer, S. C. Whitehouse, A. Mezzacappa, F. K. Thielemann, and M. Liebendorfer,
 2 “The neutrino signal from protoneutron star accretion and black hole formation,”
 3 arXiv:0809.5129 [astro-ph], 2008. Cited in Section 6.1 (pg.153).
- 4 212. R. C. Schirato and G. M. Fuller, “Connection between supernova shocks, flavor
 5 transformation, and the neutrino signal,” LA-UR-02-3068, arXiv:astro-ph/0205390
 6 [astro-ph], 2002. Cited in Section 6.1 (pg.153).
- 7 213. F. Hanke, A. Marek, B. Muller, and H.-T. Janka, “Is Strong SASI Activity the Key to
 8 Successful Neutrino-Driven Supernova Explosions?,” *Astrophys.J.* **755** (2012) 138,
 9 arXiv:1108.4355 [astro-ph.SR]. Cited in Section 6.1 (pg.153).
- 1 214. F. Hanke, B. Mueller, A. Wongwathanarat, A. Marek, and H.-T. Janka, “SASI Activity in
 2 Three-Dimensional Neutrino-Hydrodynamics Simulations of Supernova Cores,”
 3 *Astrophys.J.* **770** (2013) 66, arXiv:1303.6269 [astro-ph.SR]. Cited in
 4 Section 6.1 (pg.153).
- 5 215. A. Friedland and A. Gruzinov, “Neutrino signatures of supernova turbulence,”
 6 LA-UR-06-2202, arXiv:astro-ph/0607244 [astro-ph], 2006. Cited in
 7 Section 6.1 (pg.153).
- 8 216. T. Lund and J. P. Kneller, “Combining collective, MSW, and turbulence effects in
 9 supernova neutrino flavor evolution,” arXiv:1304.6372 [astro-ph.HE], 2013. Cited in
 10 Section 6.1 (pg.153).
- 11 217. G. G. Raffelt, “Particle Physics from Stars,” *Ann. Rev. Nucl. Part. Sci.* **49** (1999) 163–216,
 12 arXiv:hep-ph/9903472. Cited in Section 6.1 (pg.153).
- 13 218. A. Bueno, I. Gil Botella, and A. Rubbia, “Supernova neutrino detection in a liquid argon
 14 TPC,” ICARUS-TM-03-02, arXiv:hep-ph/0307222 [hep-ph], 2003. Cited in
 15 Section 6.1 (pg.153).
- 16 219. K. Scholberg *et al.*, “SNOWGLoBES: SuperNova Observatories with GLoBES.”
 17 <http://www.phy.duke.edu/~schol/snowglobes>. Cited in Section 6.2 (pg.154).
- 18 220. E. D. Church, “LArSoft: A Software Package for Liquid Argon Time Projection Drift
 19 Chambers,” arXiv:1311.6774 [physics.ins-det], 2013. Cited in
 20 Sections 6.2 (pg.154) and A.1.1 (pg.213).
- 21 221. T. Totani, K. Sato, H. E. Dalhed, and J. R. Wilson, “Future detection of supernova neutrino
 1 burst and explosion mechanism,” *Astrophys. J.* **496** (1998) 216–225,
 2 arXiv:astro-ph/9710203. Cited in Section 6.2 (pg.155).
- 3 222. J. Gava, J. Kneller, C. Volpe, and G. C. McLaughlin, “A dynamical collective calculation
 4 of supernova neutrino signals,” *Phys. Rev. Lett.* **103** (2009) 071101, arXiv:0902.0317
 5 [hep-ph]. Cited in Section 6.2 (pg.155).
- 6 223. L. Hudepohl, B. Muller, H.-T. Janka, A. Marek, and G. Raffelt, “Neutrino Signal of
 7 Electron-Capture Supernovae from Core Collapse to Cooling,” *Phys.Rev.Lett.* **104** (2010)
 8 251101, arXiv:0912.0260 [astro-ph.SR]. Cited in Section 6.2 (pg.155).

- 9 224. A. Cherry, A. Friedland, and H. Duan, “Private communication.”.
- 1 225. M. T. Keil, G. G. Raffelt, and H.-T. Janka, “Monte Carlo study of supernova neutrino
2 spectra formation,” *Astrophys.J.* **590** (2003) 971–991, arXiv:astro-ph/0208035
3 [astro-ph].
- 4 226. E. Church *et al.*, “Muon-induced background for beam neutrinos at the surface,”
5 LBNE-doc-6232, October, 2012. Cited in Sections 6.3.1 (pg.158), A.4 (pg.229),
6 and A.4 (pg.230).
- 7 227. Gehman, V. and Kadel, R, “Calculation of intrinsic and cosmogenic backgrounds in the
8 LBNE far detector for use in detection of supernova neutrinos,” LBNE-doc-8419, January,
9 2014. Cited in Section 6.3.2 (pg.159).
- 10 228. J. H. Harley *et al.*, “Report No. 094 - Exposure of the Population in the United States and
11 Canada from Natural Background Radiation,” *National Council on Radiation Protection
12 and Measurements* (2014) . <http://www.ncrppublications.org/Reports/094>. Cited
13 in Section 6.3.3 (pg.160).
- 14 229. L. Grandi, “Darkside-50: performance and results from the first atmospheric argon run,”
15 February, 2014. UCLA’s 11th Symposium on Sources and Detection of Dark Matter and
16 Dark Energy in the Universe. Cited in Section 6.3.3 (pg.160).
- 17 230. D. Leonard, P. Grinberg, P. Weber, E. Baussan, Z. Djurcic, *et al.*, “Systematic study of
18 trace radioactive impurities in candidate construction materials for EXO-200,”
19 *Nucl.Instrum.Meth.* **A591** (2008) 490–509, arXiv:0709.4524 [physics.ins-det].
20 Cited in Section 6.3.3 (pg.160).
- 21 231. D. Casper, “The Nuance neutrino physics simulation, and the future,”
22 *Nucl.Phys.Proc.Suppl.* **112** (2002) 161–170, arXiv:hep-ph/0208030 [hep-ph].
- 23 232. G. Zeller, “Nuclear Effects in Water vs. Argon,” LBNE-doc-740, 2010.
- 24 233. G. Zeller, “Expected Event Rates in the LBNE Near Detector,” LBNE-doc-783, 2010.
- 25 234. S.R.Mishra, Apr, 1990. Review talk presented at Workshop on Hadron Structure Functions
26 and Parton Distributions, Fermilab. Cited in Section 7.1.1 (pg.164).
- 27 235. R. Raja, “The Main injector particle production experiment (MIPP) at Fermilab,”
28 *Nucl.Instrum.Meth.* **A553** (2005) 225–230, arXiv:hep-ex/0501005 [hep-ex]. Cited in
1 Section 7.1.2 (pg.166).
- 2 236. J. Formaggio and G. Zeller, “From eV to EeV: Neutrino Cross Sections Across Energy
3 Scales,” *Rev.Mod.Phys.* **84** (2012) 1307, arXiv:1305.7513 [hep-ex]. Cited in
4 Sections 7.1.3 (pg.166) and 7.4.4 (pg.182).
- 5 237. W. J. Marciano and Z. Parsa, “Neutrino-Electron Scattering Theory,” *J. Phys.* **G29** (2003)
6 2629–2645, arXiv:hep-ph/0403168. Cited in Sections 7.1.4 (pg.167)
7 and 7.2.2 (pg.173).
- 8 238. S. Mishra, K. Bachmann, R. Bernstein, R. Blair, C. Foudas, *et al.*, “Measurement of
9 Inverse Muon Decay $\nu_\mu + e \rightarrow \mu^- + \nu_e$ at Fermilab Tevatron Energies 15-GeV -
10 600-GeV,” *Phys.Rev.Lett.* **63** (1989) 132–135. Cited in Section 7.1.5 (pg.167).

- 11 239. S. Mishra, K. Bachmann, R. Blair, C. Foudas, B. King, *et al.*, “Inverse Muon Decay,
12 $\nu_\mu e \rightarrow \mu^- \nu_e$, at the Fermilab Tevatron,” *Phys.Lett.* **B252** (1990) 170–176. Cited in
13 Section 7.1.5 (pg.167).
- 14 240. P. Vilain *et al.*, **CHARM-II Collaboration**, “A Precise measurement of the cross-section
15 of the inverse muon decay muon-neutrino + e- → mu- + electron-neutrino,” *Phys.Lett.*
16 **B364** (1995) 121–126. Cited in Section 7.1.5 (pg.167).
- 17 241. O. Samoylov *et al.*, **NOMAD**, “A Precision Measurement of Charm Dimuon Production
18 in Neutrino Interactions from the NOMAD Experiment,” *Nucl.Phys.* **B876** (2013)
19 339–375, arXiv:1308.4750 [hep-ex]. Cited in Sections 7.1.8 (pg.169),
20 7.2.1 (pg.172), and 7.4.4 (pg.183).
- 21 242. G. Zeller *et al.*, **NuTeV Collaboration**, “A Precise determination of electroweak
22 parameters in neutrino nucleon scattering,” *Phys.Rev.Lett.* **88** (2002) 091802,
23 arXiv:hep-ex/0110059 [hep-ex]. Cited in Section 7.2.1 (pg.170).
- 24 243. H. Abramowicz, R. Belusevic, A. Blondel, H. Blumer, P. Bockmann, *et al.*, **CDHS**
25 **Collaboration**, “A Precision Measurement of $\sin^{**2}\theta_W$ from Semileptonic
26 Neutrino Scattering,” *Phys.Rev.Lett.* **57** (1986) 298. Cited in Section 7.2.1 (pg.171).
- 27 244. J. Allaby *et al.*, **CHARM Collaboration**, “A Precise Determination of the Electroweak
28 Mixing Angle from Semileptonic Neutrino Scattering,” *Z.Phys.* **C36** (1987) 611. Cited in
1 Section 7.2.1 (pg.171).
- 2 245. P. Reutens, F. Merritt, D. MacFarlane, R. Messner, D. Novikoff, *et al.*, **CCFR**
3 **Collaboration**, “Measurement of $\sin^2 \theta_W$ and ρ in Deep Inelastic Neutrino - Nucleon
4 Scattering,” *Phys.Lett.* **B152** (1985) 404–410. Cited in Section 7.2.1 (pg.171).
- 5 246. S. Alekhin, S. A. Kulagin, and R. Petti, “Modeling lepton-nucleon inelastic scattering from
6 high to low momentum transfer,” *AIP Conf.Proc.* **967** (2007) 215–224, arXiv:0710.0124
7 [hep-ph]. Cited in Section 7.2.1 (pg.172).
- 8 247. S. Alekhin, S. A. Kulagin, and R. Petti, “Update of the global fit of PDFs including the
9 low-Q DIS data,” arXiv:0810.4893 [hep-ph], 2008. Cited in Section 7.2.1 (pg.172).
- 10 248. S. Alekhin, S. A. Kulagin, and R. Petti, “Determination of Strange Sea Distributions from
11 Neutrino-Nucleon Deep Inelastic Scattering,” *Phys.Lett.* **B675** (2009) 433–440,
12 arXiv:0812.4448 [hep-ph]. Cited in Section 7.2.1 (pg.172).
- 13 249. A. Arbuzov, D. Y. Bardin, and L. Kalinovskaya, “Radiative corrections to neutrino deep
14 inelastic scattering revisited,” *JHEP* **0506** (2005) 078, arXiv:hep-ph/0407203
15 [hep-ph]. Cited in Section 7.2.1 (pg.172).
- 1 250. S. A. Kulagin and R. Petti, “Global study of nuclear structure functions,” *Nucl.Phys.* **A765**
2 (2006) 126–187, arXiv:hep-ph/0412425 [hep-ph]. Cited in Section 7.2.1 (pg.172).
- 3 251. S. A. Kulagin and R. Petti, “Neutrino inelastic scattering off nuclei,” *Phys.Rev.* **D76** (2007)
4 094023, arXiv:hep-ph/0703033 [HEP-PH]. Cited in Sections 7.2.1 (pg.172),
5 7.4.2 (pg.181), and 7.6 (pg.186).
- 6 252. S. Kulagin and R. Petti, “Structure functions for light nuclei,” *Phys.Rev.* **C82** (2010)
7 054614, arXiv:1004.3062 [hep-ph]. Cited in Section 7.2.1 (pg.172).

- 8 253. P. Vilain *et al.*, **CHARM-II Collaboration**, “Precision measurement of electroweak
9 parameters from the scattering of muon-neutrinos on electrons,” *Phys.Lett.* **B335** (1994)
10 246–252. Cited in Section 7.2.2 (pg.173).
- 11 254. A. Czarnecki and W. J. Marciano, “Polarized Moller scattering asymmetries,”
12 *Int.J.Mod.Phys. A15* (2000) 2365–2376, arXiv:hep-ph/0003049 [hep-ph].
- 13 255. S. Bennett and C. Wieman, “Erratum: Measurement of the $6s \rightarrow 7s$ Transition
14 Polarizability in Atomic Cesium and an Improved Test of the Standard Model [Phys. Rev.
15 Lett. 82, 2484 (1999)],” *Phys.Rev.Lett.* **82** (1999) 4153–4153.
- 16 256. W. Yao *et al.*, **Particle Data Group**, “Review of Particle Physics,” *J.Phys.* **G33** (2006)
17 1–1232.
- 18 257. P. Anthony *et al.*, **SLAC E158 Collaboration**, “Precision measurement of the weak
19 mixing angle in Moller scattering,” *Phys.Rev.Lett.* **95** (2005) 081601,
20 arXiv:hep-ex/0504049 [hep-ex].
- 21 258. J. H. Lee, “The Qweak: Precision measurement of the proton’s weak charge by parity
22 violating experiment,” *Few Body Syst.* **54** (2013) 129–134. Cited in Section 7.2.2 (pg.175).
- 23 259. Nuruzzaman, “Q-weak: First Direct Measurement of the Weak Charge of the Proton,”
24 arXiv:1312.6009 [nucl-ex], 2013. Cited in Section 7.2.2 (pg.175).
- 25 260. R. Jaffe and A. Manohar, “The G(1) Problem: Fact and Fantasy on the Spin of the Proton,”
26 *Nucl.Phys.* **B337** (1990) 509–546. Cited in Section 7.3 (pg.175).
- 27 261. R. D. Young, J. Roche, R. D. Carlini, and A. W. Thomas, “Extracting nucleon strange and
28 anapole form factors from world data,” *Phys.Rev.Lett.* **97** (2006) 102002,
1 arXiv:nucl-ex/0604010 [nucl-ex]. Cited in Sections 7.3.1 (pg.175)
2 and 7.3.1 (pg.176).
- 3 262. D. B. Leinweber, S. Boinepalli, I. Cloet, A. W. Thomas, A. G. Williams, *et al.*, “Precise
4 determination of the strangeness magnetic moment of the nucleon,” *Phys.Rev.Lett.* **94**
5 (2005) 212001, arXiv:hep-lat/0406002 [hep-lat]. Cited in Section 7.3.1 (pg.175).
- 6 263. L. Ahrens, S. Aronson, P. Connolly, B. Gibbard, M. Murtagh, *et al.*, “Measurement of
7 Neutrino - Proton and anti-neutrino - Proton Elastic Scattering,” *Phys.Rev.* **D35** (1987) 785.
8 Cited in Section 7.3.2 (pg.177).
- 9 264. G. Garvey, W. Louis, and D. White, “Determination of proton strange form-factors from
10 neutrino p elastic scattering,” *Phys.Rev.* **C48** (1993) 761–765. Cited in
11 Section 7.3.2 (pg.177).
- 12 265. W. Alberico, M. Barbaro, S. M. Bilenky, J. Caballero, C. Giunti, *et al.*, “Strange
13 form-factors of the proton: A New analysis of the neutrino (anti-neutrino) data of the
14 BNL-734 experiment,” *Nucl.Phys.* **A651** (1999) 277–286, arXiv:hep-ph/9812388
15 [hep-ph]. Cited in Section 7.3.2 (pg.177).
- 16 266. A. Aguilar-Arevalo *et al.*, **MiniBooNE Collaboration**, “Measurement of the Neutrino
17 Neutral-Current Elastic Differential Cross Section on Mineral Oil at $E_\nu \sim 1$ GeV,”
18 *Phys.Rev.* **D82** (2010) 092005, arXiv:1007.4730 [hep-ex]. Cited in
19 Section 7.3.2 (pg.177).

267. L. Bugel *et al.*, **FINeSSE Collaboration**, “A Proposal for a near detector experiment on
21 the booster neutrino beamline: FINeSSE: Fermilab intense neutrino scattering scintillator
22 experiment,” FERMILAB-PROPOSAL-0937, arXiv:hep-ex/0402007 [hep-ex], 2004.
23 Cited in Section 7.3.2 (pg.178).
268. W. Leung, P. Quintas, S. Mishra, F. Sciulli, C. Arroyo, *et al.*, “A Measurement of the
24 Gross-Llewellyn-Smith sum rule from the CCFR x(F3) structure function,” *Phys.Lett.*
25 **B317** (1993) 655–659. Cited in Section 7.4.1 (pg.180).
269. A. Bodek and A. Simon, “What Do Electron and Neutrino Experiments Tell Us About
27 Nuclear Effects in the Deuteron,” *Z.Phys.* **C29** (1985) 231. Cited in
28 Sections 7.4.3 (pg.181) and 7.4.3 (pg.182).
270. G. Jones *et al.*, **Birmingham-CERN-Imperial Coll.-MPI(Munich)-Oxford-University
30 Coll. Collaboration**, “A Measurement of the Proton Structure Functions From Neutrino
31 Hydrogen and Anti-neutrino Hydrogen Charged Current Interactions,” *Z.Phys.* **C44** (1989)
32 379–384. Cited in Sections 7.4.3 (pg.181) and 7.4.3 (pg.182).
- 1 271. J. Berge, H. Burkhardt, F. Dydak, R. Hagelberg, M. Krasny, *et al.*, “A Measurement of
2 Differential Cross-Sections and Nucleon Structure Functions in Charged Current Neutrino
3 Interactions on Iron,” *Z.Phys.* **C49** (1991) 187–224.
- 4 272. D. Allasia *et al.*, **WA25 Collaboration**, “Measurement of the Neutron and Proton
5 Structure Functions From Neutrino and Anti-neutrinos Scattering in Deuterium,”
6 *Phys.Lett.* **B135** (1984) 231.
- 7 273. D. Allasia, C. Angelini, A. Baldini, L. Bertanza, A. Bigi, *et al.*, “Q**2 Dependence of the
1 Proton and Neutron Structure Functions from Neutrino and anti-neutrinos Scattering in
2 Deuterium,” *Z.Phys.* **C28** (1985) 321. Cited in Section 7.5 (pg.184).
- 3 274. U.-K. Yang *et al.*, **CCFR/NuTeV Collaboration**, “Measurements of F_2 and $xF_3^\nu - xF_3^{\bar{\nu}}$
4 from CCFR ν_μ -Fe and $\bar{\nu}_\mu$ -Fe data in a physics model independent way,” *Phys.Rev.Lett.*
5 **86** (2001) 2742–2745, arXiv:hep-ex/0009041 [hep-ex].
- 6 275. U.-K. Yang *et al.*, **CCFR/NuTeV Collaboration**, “Extraction of $R = \sigma(L) / \sigma(T)$
7 from CCFR Fe-neutrino(muon) and Fe-anti-neutrino(muon) differential cross-sections,”
8 *Phys.Rev.Lett.* **87** (2001) 251802, arXiv:hep-ex/0104040 [hep-ex].
- 9 276. M. Tzanov *et al.*, **NuTeV Collaboration**, “Precise measurement of neutrino and
10 anti-neutrino differential cross sections,” *Phys.Rev.* **D74** (2006) 012008,
11 arXiv:hep-ex/0509010 [hep-ex]. Cited in Section 7.4.4 (pg.183).
- 12 277. G. Onengut *et al.*, **CHORUS Collaboration**, “Measurement of nucleon structure
13 functions in neutrino scattering,” *Phys.Lett.* **B632** (2006) 65–75.
- 1 278. R. Petti and O. Samoylov, “Charm dimuon production in neutrino-nucleon interactions in
2 the NOMAD experiment,” *Phys.Part.Nucl.Lett.* **8** (2011) 755–761. Cited in
3 Section 7.4.4 (pg.183).
- 4 279. T. Sekiguchi, “Neutrino facility and neutrino physics in J-PARC,” *PTEP* **2012** (2012)
5 02B005. Cited in Section 7.4.4 (pg.183).

- 1 280. J. Dudek, R. Ent, R. Essig, K. Kumar, C. Meyer, *et al.*, “Physics Opportunities with the 12
2 GeV Upgrade at Jefferson Lab,” *Eur.Phys.J.* **A48** (2012) 187, arXiv:1208.1244
3 [hep-ex]. Cited in Section 7.4.4 (pg.183).
- 4 281. N. Mondal, “India-Based Neutrino Observatory (INO),” *Eur.Phys.J.Plus* **127** (2012) 106.
5 Cited in Section 7.6 (pg.185).
- 6 282. A. Butkevich, “Quasi-elastic neutrino charged-current scattering off medium-heavy nuclei:
7 40Ca and 40Ar,” *Phys.Rev.* **C85** (2012) 065501, arXiv:1204.3160 [nucl-th]. Cited in
8 Section 7.6 (pg.186).
- 9 283. A. Butkevich and S. A. Kulagin, “Quasi-elastic neutrino charged-current scattering cross
10 sections on oxygen,” *Phys.Rev.* **C76** (2007) 045502, arXiv:0705.1051 [nucl-th].
11 Cited in Section 7.6 (pg.186).
- 12 284. A. M. Ankowski and J. T. Sobczyk, “Construction of spectral functions for medium-mass
13 nuclei,” *Phys.Rev.* **C77** (2008) 044311, arXiv:0711.2031 [nucl-th]. Cited in
14 Section 7.6 (pg.186).
- 15 285. T. Asaka and M. Shaposhnikov, “The nuMSM, dark matter and baryon asymmetry of the
16 universe,” *Phys.Lett.* **B620** (2005) 17–26, arXiv:hep-ph/0505013 [hep-ph]. Cited in
17 Sections 7.7 (pg.187) and 7.7 (pg.188).
- 18 286. D. Gorbunov and M. Shaposhnikov, “How to find neutral leptons of the ν MSM?,” *JHEP*
19 **0710** (2007) 015, arXiv:0705.1729 [hep-ph]. Cited in Sections 7.7 (pg.187)
20 and 7.7 (pg.188).
- 21 287. A. Boyarsky, O. Ruchayskiy, and M. Shaposhnikov, “The Role of sterile neutrinos in
22 cosmology and astrophysics,” *Ann.Rev.Nucl.Part.Sci.* **59** (2009) 191–214,
23 arXiv:0901.0011 [hep-ph]. Cited in Section 7.7 (pg.187).
- 24 288. S. Dodelson and L. M. Widrow, “Sterile-neutrinos as dark matter,” *Phys.Rev.Lett.* **72**
25 (1994) 17–20, arXiv:hep-ph/9303287 [hep-ph]. Cited in Section 7.7 (pg.187).
- 26 289. A. Atre, T. Han, S. Pascoli, and B. Zhang, “The Search for Heavy Majorana Neutrinos,”
1 *JHEP* **0905** (2009) 030, arXiv:0901.3589 [hep-ph]. Cited in Sections 7.7 (pg.187)
2 and 7.7 (pg.188).
- 3 290. M. Shaposhnikov, “The nuMSM, leptonic asymmetries, and properties of singlet fermions,”
4 *JHEP* **0808** (2008) 008, arXiv:0804.4542 [hep-ph]. Cited in Section 7.7 (pg.187).
- 5 291. E. K. Akhmedov, V. Rubakov, and A. Y. Smirnov, “Baryogenesis via neutrino oscillations,”
6 *Phys.Rev.Lett.* **81** (1998) 1359–1362, arXiv:hep-ph/9803255 [hep-ph]. Cited in
7 Section 7.7 (pg.188).
- 8 292. A. M. Cooper-Sarkar *et al.*, **WA66 Collaboration**, “Search for Heavy Neutrino Decays in
9 the BEBC Beam Dump Experiment,” *Phys.Lett.* **B160** (1985) 207. Cited in
10 Section 7.7 (pg.188).
- 11 293. F. Bergsma *et al.*, **CHARM Collaboration**, “A Search for Decays of Heavy Neutrinos in
12 the Mass Range 0.5-GeV to 2.8-GeV,” *Phys.Lett.* **B166** (1986) 473. Cited in
13 Section 7.7 (pg.188).

14. 294. A. Vaitaitis *et al.*, **NuTeV Collaboration, E815 Collaboration**, “Search for Neutral
15. Heavy Leptons in a High-Energy Neutrino Beam,” *Phys.Rev.Lett.* **83** (1999) 4943–4946,
16. arXiv:hep-ex/9908011 [hep-ex]. Cited in Section 7.7 (pg.188).
17. 295. G. Bernardi, G. Carugno, J. Chauveau, F. Dicarlo, M. Dris, *et al.*, “Search for Neutrino
18. Decay,” *Phys.Lett.* **B166** (1986) 479. Cited in Section 7.7 (pg.188).
19. 296. G. Bernardi, G. Carugno, J. Chauveau, F. Dicarlo, M. Dris, *et al.*, “Further Limits on
20. Heavy Neutrino Couplings,” *Phys.Lett.* **B203** (1988) 332. Cited in Section 7.7 (pg.188).
21. 297. L. Canetti and M. Shaposhnikov, “Baryon Asymmetry of the Universe in the NuMSM,”
22. *JCAP* **1009** (2010) 001, arXiv:1006.0133 [hep-ph].
23. 298. C. Kullenberg *et al.*, **NOMAD Collaboration**, “A Search for Single Photon Events in
1 Neutrino Interactions in NOMAD,” *Phys.Lett.* **B706** (2012) 268–275, arXiv:1111.3713
2 [hep-ex]. Cited in Section 7.7 (pg.190).
- 3 299. C. Volpe, N. Auerbach, G. Colo, T. Suzuki, and N. Van Giai, “Neutrino C-12 reactions and
4 the LSND and KARMEN experiments on neutrino oscillations,” *Phys. Atom. Nucl.* **64**
5 (2001) 1165–1168. Cited in Section 7.8 (pg.190).
- 6 300. M. Maltoni and T. Schwetz, “Sterile neutrino oscillations after first MiniBooNE results,”
7 *Phys.Rev.* **D76** (2007) 093005, arXiv:0705.0107 [hep-ph]. Cited in
8 Section 7.8 (pg.190).
- 9 301. P. Ade *et al.*, **Planck Collaboration**, “Planck 2013 results. XVI. Cosmological
10 parameters,” arXiv:1303.5076 [astro-ph.CO], 2013. Cited in Section 7.9 (pg.192).
- 1 302. C. Bennett *et al.*, **WMAP**, “Nine-Year Wilkinson Microwave Anisotropy Probe (WMAP)
2 Observations: Final Maps and Results,” *Astrophys.J.Suppl.* **208** (2013) 20,
3 arXiv:1212.5225 [astro-ph.CO]. Cited in Section 7.9 (pg.192).
- 4 303. B. Batell, M. Pospelov, and A. Ritz, “Exploring Portals to a Hidden Sector Through Fixed
5 Targets,” *Phys.Rev.* **D80** (2009) 095024, arXiv:0906.5614 [hep-ph]. Cited in
6 Section 7.9 (pg.193).
- 7 304. P. deNiverville, M. Pospelov, and A. Ritz, “Observing a light dark matter beam with
8 neutrino experiments,” *Phys.Rev.* **D84** (2011) 075020, arXiv:1107.4580 [hep-ph].
9 Cited in Section 7.9 (pg.193).
- 10 305. P. deNiverville, D. McKeen, and A. Ritz, “Signatures of sub-GeV dark matter beams at
11 neutrino experiments,” *Phys.Rev.* **D86** (2012) 035022, arXiv:1205.3499 [hep-ph].
12 Cited in Section 7.9 (pg.193).
- 13 306. R. Dharmapalan *et al.*, **MiniBooNE Collaboration**, “Low Mass WIMP Searches with a
14 Neutrino Experiment: A Proposal for Further MiniBooNE Running,”
15 FERMILAB-PROPOSAL-1032, arXiv:1211.2258 [hep-ex], 2012. Cited in
16 Section 7.9 (pg.193).
- 17 307. H. Bethe, “Energy production in stars,” *Phys.Rev.* **55** (1939) 434–456. Cited in
18 Section 8.1 (pg.195).
- 19 308. C. Weizsäcker, “Über Elementumwandlungen im Innern der Sterne II,” *Physik.Z.* **39** (1938)
20 633–646. Cited in Section 8.1 (pg.195).

- 21 309. J. N. Bahcall, A. M. Serenelli, and S. Basu, “New solar opacities, abundances,
22 helioseismology, and neutrino fluxes,” *Astrophys.J.* **621** (2005) L85–L88,
23 arXiv:astro-ph/0412440 [astro-ph]. Cited in Section 8.1 (pg.195).
- 24 310. S. Fukuda *et al.*, **Super-Kamiokande Collaboration**, “Solar B-8 and hep neutrino
25 measurements from 1258 days of Super-Kamiokande data,” *Phys.Rev.Lett.* **86** (2001)
1 5651–5655, arXiv:hep-ex/0103032 [hep-ex]. Cited in Section 8.1 (pg.195).
- 2 311. Q. Ahmad *et al.*, **SNO Collaboration**, “Measurement of the rate of nu/e + d → p + p + e-
3 interactions produced by B-8 solar neutrinos at the Sudbury Neutrino Observatory,”
4 *Phys.Rev.Lett.* **87** (2001) 071301, arXiv:nucl-ex/0106015 [nucl-ex]. Cited in
5 Section 8.1 (pg.195).
- 6 312. G. Bellini, J. Benziger, D. Bick, S. Bonetti, G. Bonfini, *et al.*, “Precision measurement of
7 the 7Be solar neutrino interaction rate in Borexino,” *Phys.Rev.Lett.* **107** (2011) 141302,
8 arXiv:1104.1816 [hep-ex]. Cited in Section 8.1 (pg.197).
- 9 313. C. Kraus, **SNO+ Collaboration**, “SNO with liquid scintillator: SNO+,” *Prog. Part. Nucl.
10 Phys.* **57** (2006) 150–152. Cited in Section 8.1 (pg.197).
- 11 314. H. Sekiya, **Super-Kamiokande Collaboration**, “Solar neutrino analysis of
12 Super-Kamiokande,” arXiv:1307.3686, 2013. Cited in Section 8.1 (pg.197).
- 13 315. A. Guglielmi, **ICARUS Collaboration**, “Status and early events from ICARUS T600,”
14 *Nucl.Phys B (Proc. Suppl.)* **229-232** (2012) 342–346. Cited in Section 8.1 (pg.198).
- 15 316. G. Bellini *et al.*, **Borexino Collaboration**, “First evidence of pep solar neutrinos by direct
16 detection in Borexino,” *Phys.Rev.Lett.* **108** (2012) 051302, arXiv:1110.3230 [hep-ex].
- 17 317. G. Bellini *et al.*, **Borexino Collaboration**, “Measurement of the solar 8B neutrino rate
18 with a liquid scintillator target and 3 MeV energy threshold in the Borexino detector,”
19 *Phys.Rev.* **D82** (2010) 033006, arXiv:0808.2868 [astro-ph].
- 20 318. A. Gando *et al.*, **KamLAND Collaboration**, “Reactor On-Off Antineutrino Measurement
21 with KamLAND,” arXiv:1303.4667 [hep-ex], 2013. Cited in Section 8.1 (pg.199).
- 22 319. J. Silk, K. A. Olive, and M. Srednicki, “The Photino, the Sun and High-Energy Neutrinos,”
23 *Phys.Rev.Lett.* **55** (1985) 257–259. Cited in Section 8.2 (pg.199).
- 24 320. M. Cirelli, N. Fornengo, T. Montaruli, I. A. Sokalski, A. Strumia, *et al.*, “Spectra of
25 neutrinos from dark matter annihilations,” *Nucl.Phys.* **B727** (2005) 99–138,
26 arXiv:hep-ph/0506298 [hep-ph]. Cited in Section 8.2 (pg.200).
- 27 321. J. LoSecco, J. Van der Velde, R. Bionta, G. Blewitt, C. Bratton, *et al.*, “Limits on the Flux
28 of Energetic Neutrinos from the Sun,” *Phys.Lett.* **B188** (1987) 388. Cited in
1 Section 8.2 (pg.200).
- 2 322. M. Aartsen *et al.*, **IceCube Collaboration**, “Search for dark matter annihilations in the
3 Sun with the 79-string IceCube detector,” *Phys.Rev.Lett.* **110** (2013) 131302,
4 arXiv:1212.4097 [astro-ph.HE]. Cited in Section 8.2 (pg.200).
- 5 323. M. Blennow, M. Carrigan, and E. F. Martinez, “Probing the Dark Matter mass and nature
6 with neutrinos,” *JCAP* **1306** (2013) 038, arXiv:1303.4530 [hep-ph]. Cited in
7 Section 8.2 (pg.200).

- 8 324. T. Totani, K. Sato, and Y. Yoshii, “Spectrum of the supernova relic neutrino background
9 and evolution of galaxies,” *Astrophys.J.* **460** (1996) 303–312, arXiv:astro-ph/9509130
10 [astro-ph]. Cited in Section 8.3 (pg.201).
- 11 325. K. Sato, T. Totani, and Y. Yoshii, “Spectrum of the supernova relic neutrino background
12 and evolution of galaxies,” 1997. Cited in Section 8.3 (pg.201).
- 13 326. D. Hartmann and S. Woosley, “The cosmic supernova neutrino background,”
14 *Astropart.Phys.* **7** (1997) 137–146. Cited in Section 8.3 (pg.201).
- 15 327. R. Malaney, “Evolution of the cosmic gas and the relic supernova neutrino background,”
16 *Astropart.Phys.* **7** (1997) 125–136, arXiv:astro-ph/9612012 [astro-ph]. Cited in
17 Section 8.3 (pg.201).
- 18 328. M. Kaplinghat, G. Steigman, and T. Walker, “The Supernova relic neutrino background,”
19 *Phys.Rev.* **D62** (2000) 043001, arXiv:astro-ph/9912391 [astro-ph]. Cited in
20 Section 8.3 (pg.201).
- 21 329. S. Ando, J. F. Beacom, and H. Yuksel, “Detection of neutrinos from supernovae in nearby
22 galaxies,” *Phys.Rev.Lett.* **95** (2005) 171101, arXiv:astro-ph/0503321 [astro-ph].
23 Cited in Section 8.3 (pg.201).
- 24 330. C. Lunardini, “Testing neutrino spectra formation in collapsing stars with the diffuse
25 supernova neutrino flux,” *Phys.Rev.* **D75** (2007) 073022, arXiv:astro-ph/0612701
1 [astro-ph]. Cited in Section 8.3 (pg.201).
- 2 331. M. Fukugita and M. Kawasaki, “Constraints on the star formation rate from supernova relic
3 neutrino observations,” *Mon.Not.Roy.Astron.Soc.* **340** (2003) L7,
4 arXiv:astro-ph/0204376 [astro-ph]. Cited in Section 8.3 (pg.201).
- 5 332. P. Vogel and J. F. Beacom, “Angular distribution of neutron inverse beta decay,
6 anti-neutrino(e) + $p \rightarrow e^+ + n$,” *Phys.Rev.* **D60** (1999) 053003, arXiv:hep-ph/9903554
7 [hep-ph]. Cited in Section 8.3 (pg.201).
- 8 333. A. Strumia and F. Vissani, “Precise quasielastic neutrino nucleon cross section,” *Phys. Lett.*
9 **B564** (2003) 42–54, arXiv:astro-ph/0302055. Cited in Section 8.3 (pg.201).
- 10 334. W. E. Ormand, P. M. Pizzochero, P. F. Bortignon, and R. A. Broglia, “Neutrino capture
11 cross-sections for Ar-40 and Beta decay of Ti-40,” *Phys. Lett.* **B345** (1995) 343–350,
1 arXiv:nucl-th/9405007. Cited in Section 8.3 (pg.201).
- 2 335. E. Kolbe, K. Langanke, G. Martinez-Pinedo, and P. Vogel, “Neutrino nucleus reactions and
3 nuclear structure,” *J. Phys.* **G29** (2003) 2569–2596, arXiv:nucl-th/0311022. Cited in
4 Section 8.3 (pg.201).
- 5 336. M. Sajjad Athar and S. K. Singh, “nu/e (anti-nu/e) - Ar-40 absorption cross sections for
6 supernova neutrinos,” *Phys. Lett.* **B591** (2004) 69–75. Cited in Section 8.3 (pg.201).
- 7 337. A. Cocco, A. Ereditato, G. Fiorillo, G. Mangano, and V. Pettorino, “Supernova relic
8 neutrinos in liquid argon detectors,” *JCAP* **0412** (2004) 002, arXiv:hep-ph/0408031
9 [hep-ph]. Cited in Section 8.3 (pg.202).
- 10 338. R. Abbasi *et al.*, **IceCube Collaboration**, “Search for Relativistic Magnetic Monopoles
11 with IceCube,” *Phys.Rev.* **D87** (2013) 022001, arXiv:1208.4861 [astro-ph.HE]. Cited
12 in Section 8.4 (pg.203).

- 13 339. M. Aartsen *et al.*, **IceCube Collaboration**, “The IceCube Neutrino Observatory Part IV:
14 Searches for Dark Matter and Exotic Particles,” arXiv:1309.7007 [astro-ph.HE],
15 2013. Cited in Section 8.4 (pg.203).
- 16 340. K. Ueno *et al.*, **Super-Kamiokande Collaboration**, “Search for GUT Monopoles at
17 Super-Kamiokande,” *Astropart.Phys.* **36** (2012) 131–136, arXiv:1203.0940 [hep-ex].
18 Cited in Section 8.4 (pg.203).
- 19 341. M. Aartsen *et al.*, **IceCube Collaboration**, “Search for non-relativistic Magnetic
20 Monopoles with IceCube,” arXiv:1402.3460 [astro-ph.CO], 2014. Cited in
21 Section 8.4 (pg.203).
- 22 342. M. Ambrosio *et al.*, **MACRO Collaboration**, “Final results of magnetic monopole
23 searches with the MACRO experiment,” *Eur.Phys.J.* **C25** (2002) 511–522,
24 arXiv:hep-ex/0207020 [hep-ex]. Cited in Section 8.4 (pg.203).
- 1 343. R. Mohapatra, “Neutron-Anti-Neutron Oscillation: Theory and Phenomenology,” *J.Phys.*
2 **G36** (2009) 104006, arXiv:0902.0834 [hep-ph]. Cited in Section 8.5 (pg.204).
- 3 344. The United States Department of Energy, “Program and Project Management for the
4 Acquisition of Capital Assets,” DOE, DOE O 413.3B, November, 2010. Cited in
5 Section 9.1 (pg.206).
- 6 345. J. Strait, R. Wilson, and V. Papadimitriou, “LBNE Presentations to P5,” LBNE-doc-8694,
7 November, 2013. Cited in Section 9.1 (pg.207).
- 8 346. S. Bilenky and C. Giunti, “Neutrinoless double-beta decay: A brief review,” *Mod.Phys.Lett.*
9 **A27** (2012) 1230015, arXiv:1203.5250 [hep-ph]. Cited in Section 9.2 (pg.209).
- 10 347. **LBNE Project Management Team**, “LBNE Conceptual Design Report: The LBNE
11 Water Cherenkov Detector,” LBNE-doc-5118, 2012. Cited in Section 9.3 (pg.210).
- 12 348. J. Hewett, H. Weerts, K. Babu, J. Butler, B. Casey, *et al.*, “Planning the Future of U.S.
13 Particle Physics (Snowmass 2013): Chapter 2: Intensity Frontier,”
14 FERMILAB-CONF-14-019-CH02, arXiv:1401.6077 [hep-ex], 2014. Cited in
15 Section 9.4.1 (pg.210).
- 16 349. C. Green, J. Kowalkowski, M. Paterno, M. Fischler, L. Garren, *et al.*, “The art framework,”
17 *J.Phys.Conf.Ser.* **396** (2012) 022020. Cited in Section A.1.1 (pg.213).
- 18 350. T. Katori, **MicroBooNE Collaboration**, “MicroBooNE, A Liquid Argon Time Projection
19 Chamber (LArTPC) Neutrino Experiment,” *AIP Conf.Proc.* **1405** (2011) 250–255,
20 arXiv:1107.5112 [hep-ex]. Cited in Sections A.1.1 (pg.213) and A.3 (pg.221).
- 21 351. M. Soderberg, **ArgoNeuT Collaboration**, “ArgoNeuT: A Liquid Argon Time Projection
22 Chamber Test in the NuMI Beamline,” FERMILAB-CONF-09-516-E, arXiv:0910.3433
23 [physics.ins-det], 2009. Cited in Section A.1.1 (pg.213).
- 24 352. D.Huffman, “A Method for the Construction of Minimum-Redundancy Codes,” in
25 *Proceedings of the IRE*. 1952. Cited in Section A.1.1 (pg.215).
- 26 353. M. Szydagis, N. Barry, K. Kazkaz, J. Mock, D. Stolp, *et al.*, “NEST: A Comprehensive
27 Model for Scintillation Yield in Liquid Xenon,” *JINST* **6** (2011) P10002,
28 arXiv:1106.1613 [physics.ins-det]. Cited in Section A.1.1 (pg.215).

- 29 354. C. Hagman, D. Lange, J. Verbeke, and D. Wright, “Cosmic-ray Shower Library (CRY),”
30 Lawrence Livermore National Laboratory, UCRL-TM-229453, March, 2012.
31 http://nuclear.llnl.gov/simulation/doc_cry_v1.7/cry.pdf. Cited in
32 Section A.1.1 (pg.216).
- 33 355. R. P. Sandhir, S. Muhuri, and T. Nayak, “Dynamic Fuzzy c-Means (dFCM) Clustering and
34 its Application to Calorimetric Data Reconstruction in High Energy Physics,”
35 *Nucl.Instrum.Meth.* **A681** (2012) 34–43, arXiv:1204.3459 [nucl-ex]. Cited in
1 Section A.2 (pg.218).
- 2 356. R. E. Kalman, “A new approach to linear filtering and prediction problems,” *Transactions*
3 *of the ASME-Journal of Basic Engineering* **82** no. Series D, (1960) 35–45. Cited in
4 Section A.2 (pg.218).
- 5 357. J. Marshall and M. Thomson, “The Pandora software development kit for particle flow
6 calorimetry,” *J.Phys.Conf.Ser.* **396** (2012) 022034. Cited in Section A.2 (pg.219).
- 7 358. A. Accardi, J. Albacete, M. Anselmino, N. Armesto, E. Aschenauer, *et al.*, “Electron Ion
8 Collider: The Next QCD Frontier - Understanding the glue that binds us all,”
9 BNL-98815-2012-JA, JLAB-PHY-12-1652, arXiv:1212.1701 [nucl-ex], 2012. Cited
10 in Sections B (pg.233) and B (pg.235).